ELEMENT 5 – WATER QUALITY MONITORING (2012)

The Department of Water Resources (DWR) has been monitoring water quality as part of the South Delta Temporary Barriers project since 1991 to investigate water quality conditions in the South Delta that may be affected by temporary barrier installations and operations. In 2012, DWR continued its South Delta water quality sampling program, which consisted of continuous sampling only. DWR stopped the bi-monthly discrete water quality sampling of biological constituents and nutrients after 2010. The information collected by this program is required for compliance with a 401 Water Quality Certification issued by the Central Valley Regional Water Quality Control Board. For detailed information on the South Delta Improvements Program and the Temporary Barriers Project please visit DWR's Bay-Delta Office website at http://baydeltaoffice.water.ca.gov/sdb/.

Historically, DWR conducted discrete sampling on a weekly basis at 10 locations to monitor physical and biological constituents, as well as nutrients. The objective of this discrete program was to monitor the effects of barrier operations on water quality. To ensure that adequate data was collected before, after, and during the operational period of the barrier, DWR started discrete sampling two weeks before the barriers were installed and did not conclude until two weeks after all the barriers were removed. Staff conducted sampling every Tuesday morning to target the time when dissolved oxygen concentrations tend to be lowest.

In 1998, Central District[1] (CD) initiated a pilot program to test the viability of establishing permanent multi-parameter water quality stations in the South Delta to continuously monitor water temperature, pH, dissolved oxygen, specific conductance, and turbidity. CD established this program to better understand barrier installations in accordance with the following: 1) to determine the feasibility of collecting reliable time-series water quality data; 2) to develop an understanding of dynamic water quality conditions in a tidally influenced system; and 3) to establish and maintain long-term continuous data records in the South Delta for analysis.

This continuous water quality monitoring program began with two stations: Old River at Tracy Wildlife Association and Middle River at Howard Road. Central District staff determined that the time-series data generated from these two sites was reliable, accurate, and precise when compared to calibration standards and field data. The success of the pilot program resulted in the decision to expand the continuous monitoring program. DWR designed this expansion to complement the existing discrete stations. As a result, CD staff installed continuous monitoring stations at each of the 10 discrete monitoring locations between 2000 and 2006. After the installation of multi-parameter instruments at the discrete locations was complete, the weekly dissolved oxygen sampling was terminated and monitoring was changed from weekly to bi-monthly. This bi-monthly discrete sampling of biological constituents and nutrients was terminated after 2010.

In 2005, DWR drafted a monitoring proposal for the South Delta Permanent Barriers Project that included the implementation of three new continuous multi-parameter water quality stations. The proposed station locations were Grant Line Canal near Old River, Victoria Canal, and Doughty Cut above Grant Line Canal. The water quality instruments at Grant Line Canal near Old River and Victoria Canal were co-located with an acoustic doppler current profiler instrument, which provides time-series water quality data that could be correlated with time-series flow data. The purpose of the Doughty Cut station was to document possible improvements to water quality based on permanent barrier operation. In addition, all three of these stations provide water quality information for the calibration and validation of the DSM2 model for the South Delta. CD staff installed multi-parameter water quality stations at Doughty Cut above Grant Line Canal in 2006 and at Victoria Canal and Grant Line Canal near Old

[1] As of 2010, the Central District is now named North Central Region Office (NCRO) due to reorganization.

River in 2007. The data collected at these three sites are included in this chapter for data evaluation and analysis purposes.

In addition to satisfying the monitoring and reporting requirements mandated by the 401 Water Quality Certification for the Temporary Barriers Project, DWR staff will address the following questions in this chapter:

1) How do the water quality data collected at all of the sites compare to established water quality standards specifically for pH and dissolved oxygen?
2) Are the dissolved oxygen concentrations significantly different at the sites closest to the temporary barriers compared to the sites further upstream and/or downstream in the same waterbody?
3) For the above two questions, do the analyses differ among seasons?

MATERIALS AND METHODS

Station Locations

DWR collects continuous water quality data at thirteen monitoring stations in the South Delta: four in Middle River, four in Old River, four in Grant Line Canal and one in Victoria Canal. Figure 5-1 illustrates these site locations, and Table 5-1 provides the station coordinates and the date the station was established. DWR provides real-time data for nine of the thirteen South Delta stations on the DWR California Data Exchange Center (CDEC) website:

- Doughty Cut above Grant Line Canal
- Grant Line Canal at Tracy Blvd
- Grant Line Canal near Old River
- Middle River at Howard Road
- Middle River at Union Point
- Old River at Tracy Wildlife Association
- Old River downstream of the ORT barrier
- Old River upstream of the ORT barrier
- Victoria Canal

To access data for these stations select "real-time data" from the main menu on the CDEC website (http://cdecgov.water.ca.gov/), and then enter in the three digit station identification code. Table 5-1 provides the CDEC station codes. In addition, DWR operates three of the thirteen South Delta stations in conjunction with USGS flow stations:

- Grant Line Canal near Old River
- Old River downstream of the ORT barrier
- Victoria Canal

Table 5-1: Continuous Monitoring Station Coordinates and Date of Establishment.

Station Name	Latitude	Longitude	Date Established	CDEC Code
Doughty Cut above Grant Line Canal	37º 48' 53.0"	-121º 25' 30.8"	June 19th, 2006	DGL
Grant Line Canal above the GLC barrier	37º 49' 12.7"	-121º 26' 42.1"	March 24th, 2006	----
Grant Line Canal at Tracy Blvd	37º 49' 12.4"	-121º 26' 59.4"	March 6th, 2006	GCT
Grant Line Canal near Old River	37º 49' 12.4"	-121º 32' 40.6"	February 2nd, 2007	GLC
Middle River at Howard Road	37º 52' 34.4"	-121º 22' 59.9"	October 1st, 1999	MHO
Middle River at Undine Road	37º 50' 02.2"	-121º 23' 08.6"	June 4th, 2002	MRU
Middle River at Union Point	37º 53' 26.8"	-121º 29' 18.1"	February 23rd, 2006	MUP
Middle River near Tracy Blvd	37º 52' 53.2"	-121º 28' 02.5"	January 1st, 2003	----
Old River at Tracy Wildlife Association	37º 48' 10.1"	-121º 27' 26.7"	July 14th, 1999	TWA
Old River downstream of the ORT barrier	37º 48' 39.5"	-121º 32' 39.9"	January 18th, 2006	ODM
Old River at Head	37º 49' 09.8"	-121º 21' 36.4"	January 1st, 2001	----
Old River upstream of the ORT barrier	37º 48' 36.9"	-121º 32' 31.9"	January 1st, 2000	OAD
Victoria Canal	37º 52' 15.5"	-121º 31' 47.9"	March 30th, 2007	VCU

Site #	Location
1	Old River at Head
2	Old River at Tracy Wildlife Association
3	Old River upstream of the ORT barrier
4	Old River downstream of the ORT barrier
5	Middle River at Undine Road
6	Middle River at Howard Road
7	Middle River near Tracy Blvd
8	Middle River at Union Point
9	Doughty Cut above Grant Line Canal
10	Grant Line Canal above the GLC barrier
11	Grant Line Canal at Tracy Blvd
12	Grant Line Canal near Old River
13	Victoria Canal

Figure 5-1: Continuous Monitoring Locations for the South Delta Temporary Barriers Project

Instrumentation

DWR collects data for the following constituents in 15 minute intervals at a 1 meter depth by deploying Yellow Spring Instrument (YSI) 6600 sondes:

- water temperature (ºC)
- dissolved oxygen (mg/L)
- pH
- specific conductance (µS/cm)
- turbidity (NTU)
- chlorophyll (µg/L)

YSI 6600 sondes are approximately two feet long and three and half inches in diameter. They are completely submersible and self-contained, operating on a minimum of 9 volts of battery power from 8 C-cell alkaline batteries. Deployment data are logged in each sonde's internal memory. Sondes are capable of sampling at many different user-specified frequencies. During 2000, DWR staff used an hourly sampling frequency for all stations, which is approximately 732 samples per month. In 2001, the sampling frequency was changed to a 15-minute interval, approximately 2,920 samples per month. The change to 15-minute intervals allows for a more in-depth review of tidal factors that influence water quality. For detailed information on YSI instrumentation visit www.ysi.com.

At each monitoring site, a sonde is vertically housed within a 4" diameter PVC pipe in the water column and suspended at a depth of approximately 1 meter. To adjust for changing tides, DWR staff installed floats to maintain the 1 meter depth. To discourage vandalism the pipes are covered at the top with an end-cap and locked with master locks through two 0.5" diameter bolts. The installation pipes have 2.25 inch diameter holes along the length of the pipe spaced approximately 8 to 10 inches on center. Four sets of holes are arranged longitudinally at 90º angles from each other. These holes allow ambient water to adequately contact the sonde sensors to ensure accurate data collection. At each site, the sonde installation pipe is either lag-bolted into an existing float structure (wooden boat dock), steel-banded to a pump platform durable enough to withstand long-term usage, or bracketed to a USGS pile.

In addition to the YSI 6600 sondes, DWR staff use three other field instruments to test the validity of the sonde data:

- YSI-63 handheld unit that measures water temperature, pH, and specific conductance
- YSI Pro-ODO Luminescent Dissolved Oxygen handheld unit to check dissolved oxygen concentrations
- HACH 2100P turbidimeter to measure turbidity

Data Collection

DWR staff clean and calibrate each sonde before deployment to ensure each probe is operating correctly before being used in the field. Calibration methods for each constituent are based on YSI's Principles of Operations. In addition, the three handheld units are calibrated regularly according to the following schedule:

- The pH probe on the YSI-63 unit and the YSI Pro-ODO dissolved oxygen unit are calibrated every time before they are used in the field.
- The specific conductance probe on the YSI-63 unit is calibrated once a month.
- The HACH 2100P turbidimeter is calibrated every three months.

During the fall and winter months, sondes are typically deployed for a three-week period, after which staff exchange it with a clean and newly calibrated sonde. DWR staff use a two-week rotational period during the warmer and more biologically productive spring and summer months to reduce biological growth on the probe surfaces. When visiting a station to exchange sondes, DWR staff measure water temperature, specific conductance, pH, dissolved oxygen, and turbidity data at a 1 meter depth with the three handheld field instruments mentioned in the above section. In addition, staff collect a chlorophyll *a* sample in a plastic quart bottle at 1 meter depth with a Van Dorn sampling device. The chlorophyll *a* sample and other field measurements are sampled at a 1 meter depth since the YSI 6600 sondes are also sampling at this depth. During each field run, DWR staff also collects a duplicate chlorophyll *a* sample at one of the stations to test for field and lab precision and repeatability.

Immediately after the chlorophyll *a* samples are collected, DWR staff store them in a cooler that contains ice to preserve the samples at 4ºC and to keep them out of the sunlight. DWR staff filter the chlorophyll *a* samples at the NCRO water quality lab by passing approximately 500 mL of sample water through a 47 mm diameter glass fiber filter with a 1.0 μm pore size at a pressure of 10 inches of mercury. After filtration, the filters are immediately frozen in a freezer and transported to DWR's Bryte Laboratory within 28 days for analysis. Bryte Laboratory uses Standard Method 10200 H (Spectrometric Determination of Chlorophyll) to analyze the chlorophyll *a* samples. The data from the chlorophyll *a* field samples are used to adjust the chlorophyll *a* concentrations measured by the sondes, which is described in a later section.

Post-deployment Quality Assurance

After the YSI 6600 sondes are removed from the field, DWR staff perform the following two procedures to check whether the sondes are still operating properly and measuring accurately:

- A post-deployment accuracy check on the day the sondes are removed and before the instruments are cleaned
- A comparison between the data measured by the handheld field instruments and the data collected by the sonde at the closest 15 minute time interval

The accuracy of sonde probes while deployed in the field can be negatively affected by probe malfunction, drift away from initial calibration, and/or fouling caused by biological growth on the probe reading surface. DWR staff perform the post-deployment accuracy check by the following procedure prior to cleaning the sonde probes:

1) Placing the sonde probes in fresh calibration standards with known values
2) Operating the sondes in the standards and recording the values the sondes are reading
3) Rating the values collected during the accuracy check for each constituent as excellent, good, fair, or poor based on their deviation from the calibration standard according to the USGS technical report "Guidelines and Standard Procedures for Continuous Water Quality Monitors-Station Operation, Record Computation, and Data Reporting" (Wagner et al., 2006)

The ratings obtained from the accuracy check indicate the quality, accuracy, and reliability of the data that the sonde collected while in the field.

In addition to the post-deployment accuracy check, DWR staff compare the water temperature, specific conductance, pH, dissolved oxygen, and turbidity data measured in the field by the handheld instruments (the YSI-63, YSI Pro-ODO, and HACH 2100P) to the sonde data that is closest in time. While taking the field measurements, DWR staff attempt to collect the field readings at the same depth that the sonde probes are measuring at (1 meter) and as close to the sonde pipe as possible. Since the field instruments are calibrated regularly, a large difference between the sonde and field readings could indicate inaccuracy of the sonde data during the deployment period. DWR staff consider these comparisons between the field and sonde readings and the ratings obtained from the post-deployment accuracy check while assessing data quality when entering the continuous data into the Hydstra database.

Data Quality Assurance/Quality Control (QA/QC)

DWR staff import the data files from the sondes into the NCRO Hydstra database where additional QA/QC procedures are performed. In addition to documenting the results of the quality assurance procedures discussed in the previous section, staff use the results of these procedures to flag any suspect or unreliable data. Also, any obvious outliers in the continuous dataset due to fouling or other factors are flagged as unreliable. None of the data that has been determined by DWR staff as suspect or unreliable were used in this chapter; only data that are considered reliable and of good quality were used. The reliable and good quality data in Hydstra are used to populate the Water Data Library where the data for all the continuous sites are available online at http://wdl.water.ca.gov/.

Chlorophyll *a* estimation

Chlorophylls are complex phyto-pigment molecules found in all photosynthetic organisms, including plants and phytoplankton. There are several types of chlorophyll identified by slight differences in their molecular structure and constituents. These types include chlorophyll *a*, *b*, *c*, and *d*. Chlorophyll *a* is the principal photosynthetic pigment common to all phytoplankton and is therefore used as a measurement of the primary phytoplankton biomass.

The chlorophyll probes used on the YSI 6600 sondes emit a blue light with a peak wavelength of 470 nm. The chlorophyll within the water passing by the probe absorbs this blue light from the probe and then emits or fluoresces light with a wavelength of 650-700 nm. The amount of fluorescence from the chlorophyll is then quantified by a photodetector on the probe. Currently, YSI chlorophyll probes cannot distinguish between the slight difference in fluorescence from chlorophylls *a, b, c*, and *d*, which causes inaccuracy when attempting to quantify chlorophyll *a* concentrations.

To more accurately calculate chlorophyll *a* concentrations, DWR staff take water samples in the field for chlorophyll *a* analysis at Bryte Laboratory. Laboratory analysis is the most accurate method of measuring chlorophyll *a* concentrations. This method involves extracting chlorophyll from cells and using a spectrometer which specifically measures chlorophyll *a* without interference from other chlorophyll species (*b*, *c*, or *d*).

DWR staff used the chlorophyll *a* data from the lab to adjust the YSI sonde chlorophyll data by using an equation generated from regression analysis. This was done by first matching the lab data with the corresponding sonde chlorophyll values measured closest in time. For example, the data for a chlorophyll *a* field sample collected at 9:55 am was matched with the sonde time-series value at the 15-minute time interval closest to 9:55 am, which would be at 10:00 am. If DWR staff happened to collect a duplicate field sample at this location, then the average of the two values would be used in the analysis.

In past years of this report, staff used all of the chlorophyll data collected, including those collected during earlier years, to provide a larger data set to develop a more robust regression model; however, scatterplots of the matched sonde and lab chlorophyll data indicate that at some of the stations the relationship between these two variables may have been different in 2012 when compared to the years prior. This may be due to the very wet winter and spring in Northern and Central California during 2012. In order to determine if the relationship between the sonde and lab chlorophyll data for 2012 was significantly different than the relationship between these two variables during the years prior, staff used an analysis of covariance procedure (ANCOVA). The decision process to use chlorophyll data collected prior to 2012 is as follows:

- If the ANCOVA statistical test indicated that a significant difference existed between the relationship of the 2012 data and the relationship of the earlier data, then staff only used the 2012 chlorophyll data for the regression analysis. In this case it would be inaccurate to use the data that was collected prior to 2012 since this earlier data represents conditions when the underlying relationship between the lab and sonde chlorophyll data was different.

- If the ANCOVA procedure indicated that a significant difference did not exist between the relationship of the 2012 data and the relationship of the earlier data, then staff used all of the available chlorophyll data for the regression analysis.

The results of these statistical tests are shown in Table 5-2 in the "Regression Method" column.

After all of the chlorophyll data was compiled, DWR staff then used the Minitab statistical software to analyze regression relationships for the matched chlorophyll data pairs. Each of the 13 continuous monitoring locations was analyzed individually since the relationship between lab and sonde data is specific to location. Each regression analysis generated an equation describing the relationship between sonde and lab chlorophyll data for the particular location. DWR staff then used these equations to adjust the chlorophyll concentrations from the sonde to more closely represent chlorophyll *a* concentrations. The regression analysis procedure is described in the following steps:

1) A simple linear regression analysis is performed with the sonde data as the explanatory variable (x-variable) and the laboratory data as the response variable (y-variable). Three assumptions of this parametric regression procedure are: the data follow a linear pattern, the underlying distribution of the data follows a normal or bell-shaped curve, and the variance of the residuals from the regression is constant. If these three assumptions are met, then the equation from the linear regression analysis can be used to adjust chlorophyll *a* concentrations. Next, the seasonal terms, sine and cosine, are added to the regression analysis, which is described more in step #3. If one or more of the three assumptions of parametric regression models are not met, move on to step #2.
2) If the data do not follow a linear pattern, the explanatory variable (sonde data) needs to be transformed so that this assumption is met. If the variance of the residuals is not constant or the underlying data is not normally distributed, then the response variable (laboratory data) needs to be transformed. A typical transformation that is effective for this data is the natural logarithm. Once the response variable is transformed, the regression equation no longer predicts the mean chlorophyll *a* concentration; it predicts the geometric mean or median. In order to correct for this, either of two methods can be used: the Maximum Likelihood Estimator (MLE) or Smearing. These methods are described more in Step #4. If transforming the data allows for the three assumptions of a linear regression to be met, move on to step #3 and then step #4. If it is not possible to transform the data so that the three regression assumptions are satisfied, then a nonparametric regression needs to be used, which is described in Step #5.
3) If the equation from either the simple linear regression (Step #1) or the linear regression with transformed data (Step #2) is going to be used, then the seasonal terms, sine and cosine, are added to the regression analysis to determine if they are good predictors of the seasonality of chlorophyll concentrations. If one or both of the seasonal terms are statistically significant in the analysis, then both terms are added to the regression equation in order to incorporate seasonality into the equation. If transformation was not necessary to develop the regression equation, then the model is ready to use to adjust chlorophyll *a* concentrations. However, if transformation was necessary, then the equation is ready to use with the addition of one of the bias correction methods described in step #4.
4) MLE is one of the bias correction methods used to estimate the mean concentration when using a regression equation with the response variable transformed to a natural logarithm. The MLE is calculated by the following equation:

   $$\text{MLE} = e^{(0.5 * \text{MSE})}$$

   The MSE is the mean squared error in logarithmic units, which is a quantification of the difference between the true data and the data estimated by the regression equation. The adjusted chlorophyll *a* data generated by the regression equation with a natural logarithm transformation is then corrected by multiplying the adjusted value by the MLE. For all of the stations that had a regression equation with data transformed to natural logarithms, the MLE was used as the bias correction factor to estimate the mean chlorophyll *a* concentrations. The Smearing correction factor was not used as a bias correction factor for any of the stations, since the MLE was the better estimator[2].

5) If transforming the data doesn't allow for the assumptions of a linear regression to be attained, then the Theil-Sen line, a nonparametric regression procedure, can be calculated. Like with the linear regression when the response variable is transformed to the natural logarithm, the Theil-Sen line equation predicts the median chlorophyll *a* concentration. However, there is no bias correction factor available to estimate the mean concentrations when using a nonparametric regression procedure. Therefore, when summarizing chlorophyll *a* concentrations adjusted with the Theil-Sen equation, statistics such as daily or monthly averages cannot be reliably calculated.

The regression procedures, equations, and bias correction factors used for all 13 continuous monitoring locations are provided in Table 5-2. After DWR staff generated the regression equations for each of the monitoring locations, each 15-minute chlorophyll value recorded by the sonde was adjusted by using the equation for the particular location. If the natural logarithm transformation was used for the response variable (y variable), then staff had to use the natural exponent (e) to "back-transform" each 15-minute value to convert to the correct units, and then multiply each value by the MLE to estimate the mean adjusted concentration. Staff used these adjusted chlorophyll *a* values when calculating summary statistics or when performing other statistical analyses.

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[2] The decision to use the MLE or Smearing correction factor was determined by the following procedure. The sonde chlorophyll data that was matched to the lab chlorophyll data was plugged into the regression equation and then corrected by the MLE factor to provide a predicted sonde chlorophyll concentration. These predicted values were then matched with their corresponding lab chlorophyll values, and a linear regression was performed on the matching pairs. The same procedure was used with the Smearing correction factor. The correction factor that gave a regression equation with a slope closest to one was then used.

Table 5-2: Information from Regression Analysis for the Continuous Monitoring Locations

Station Name	Regression Method	Regression Equation [a]	MLE or Smearing Correction Factor [b]
Doughty Cut above Grant Line Canal	Theil-Sen Line of 2006-2012 data	Adjusted Chl = 2.147*(Sonde Chl) - 2.332	----
Grant Line Canal above Barrier	Linear Regression of just 2012 data	ln Adjusted Chl = 1.33*ln(Sonde Chl) - 0.585	1.129
Grant Line Canal at Tracy Blvd	Lab: Sonde Ratio of 2006-2012 data	Adjusted Chl = 1.674*(Sonde Chl)	----
Grant Line Canal near Old River	Linear Regression of 2007-2012 data	ln Adjusted Chl = 1.22*ln(Sonde Chl) - 0.486	1.198
Middle River at Howard Road	No Equation Used [c]	No Equation Used	----
Middle River at Undine Road	Lab: Sonde Ratio of 2006-2012 data	Adjusted Chl = 1.982*(Sonde Chl)	----
Middle River at Union Point	No Equation Used	No Equation Used	----
Middle River near Tracy Blvd	Linear Regression of 2006-2012 data	ln Adjusted Chl = 0.174*(Sonde Chl) + 0.25	1.135
Old River at Tracy Wildlife Association	Linear Regression of 2005-2012 data	ln Adjusted Chl = 1.37*ln(Sonde Chl) - 0.390	1.116
Old River downstream DMC Barrier	Linear Regression of 2006-2012 data	ln Adjusted Chl = 1.60*ln(Sonde Chl) - 1.12	1.193
Old River near Head	Linear Regression of just 2012 data	ln Adjusted Chl = 0.987*ln(Sonde Chl) + 0.710	1.318
Old River upstream DMC Barrier	Linear Regression of 2005-2012 data	ln Adjusted Chl = 1.13*ln(Sonde Chl) - 0.212	1.220
Victoria Canal	No Equation Used [d]	No Equation Used	----

[a] "ln" signifies the natural logarithm function. When the seasonal terms, sin(2πT) and cos(2πT), are used "π" signifies the constant pi (3.141593) and "T" signifies decimal time.

[b] The MLE was used at all of the stations with transformed response variables (y variables).

[c] No equation was used to adjust chlorophyll concentrations because both the simple linear regression (p-value=0.32) and the Theil-Sen line (p-value=0.09) were not significant.

[d] No equation was used to adjust chlorophyll concentrations since there wasn't enough data in the higher concentration range to define the relationship. In addition, the Theil-Sen equation was not statistically significant.

Data Analysis

Staff used descriptive statistics, including monthly mean, median, maximum, minimum, and standard deviation to summarize and compare the continuous data for each constituent measured by the sondes at all 13 stations. To illustrate seasonal and annual trends, staff also calculated and graphed daily means (or medians), maximums, and minimums for each constituent at all 13 stations.

In addition to those discussed above, DWR staff performed the following analyses on the continuous data to address the preceding questions:

Question: How often did the pH and dissolved oxygen data collected at all of the stations exceed established water quality standards? Does the number of times the data exceeded the standards differ depending upon the season?

Analysis: To compare the data with established pH and dissolved oxygen water quality standards, staff calculated the number of sonde data points collected at each station that exceeded the particular standard. In addition, the analyses were separated by season[3] to determine if there were any seasonal trends. Staff also calculated the percent of samples exceeding a particular standard relative to the total number of samples collected during each season. The established water quality standards are 8.50 units for pH[4] and 5.0 mg/L for dissolved oxygen[5] (CVRWQCB, 2009; USEPA, 1986). A dissolved oxygen sample less than 5.0 mg/L or a pH sample greater than 8.50 units exceeded the standard.

Question: Do the dissolved oxygen concentrations differ between stations located along a particular water body (Old River, Middle River, and Grant Line Canal) depending upon the season?

Analysis: Staff used Kruskal-Wallis hypothesis tests and Dunn's multiple comparison procedures[6], which are nonparametric statistical analyses, to determine if the stations located along the same water body had significant differences in their dissolved oxygen concentrations. Staff placed each station into one of three water body groups, and then analyzed each water body group separately to determine if there were significant differences between the sites within the group. The continuous water quality stations were grouped in the following way:

- Old River: Old River at Head, Old River at Tracy Wildlife Association, Old River upstream of the ORT barrier, and Old River downstream of the ORT barrier
- Middle River: Middle River at Undine Road, Middle River at Howard Road, Middle River near Tracy Blvd, and Middle River at Union Point
- Grant Line Canal: Doughty Cut above Grant Line Canal, Grant Line Canal above the GLC barrier, Grant Line Canal at Tracy Blvd, and Grant Line Canal near Old River

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3 Staff defined the seasons as follows: Winter (December-January), Spring (March – May), Summer (June-August), Fall (September – November).

4 The Sacramento and San Joaquin River Basin Plan states that the pH should not be above 8.50 units for all water bodies without a site-specific objective (CVRWQCB, 2009).

5 The USEPA has established National Ambient Water Quality Criteria for inorganic constituents, including dissolved oxygen, to protect freshwater aquatic life. However, there is considerable variability in dissolved oxygen tolerances among fish and other aquatic life. For a warm water system like the Delta, minimum dissolved oxygen criteria for early aquatic life stages including embryos, larvae, and less than 30-day old juveniles is 5 mg/L and 3 mg/L for other life stages including older juveniles and adults (USEPA, 1986). In addition the Sacramento and San Joaquin River Basin Plan states that within the legal boundaries of the Delta, dissolved oxygen concentrations should not be reduced below 5.0 mg/L in all water bodies except for the Sacramento River below the I Street Bridge, all waters west of the Antioch Bridge, and the San Joaquin River between Turner Cut and Stockton (these Delta water bodies have site-specific water quality objectives for dissolved oxygen; CVRWQCB, 2009).

6 Staff used daily medians in these hypothesis tests since using the raw data collected every 15 minutes introduces very strong serial correlation among the data. Performing hypothesis test on strongly serial-correlated data causes the test results to be "too significant" or the p-values are too low. One way to minimize this is to take daily medians or means of the data and use those in the hypothesis test. Daily medians or means can still be serial-correlated, but much less so than data collected every 15 minutes. In this case, staff used daily medians for the nonparametric hypothesis tests since these tests are used to compare median concentrations. In addition, the median summary statistic is resistant to outliers in the data and provides a typical value for the time period summarized.

Furthermore, staff performed these analyses separately for the spring, summer, and fall seasons (defined the same as in the water quality standard analysis) to determine if there were any seasonal trends. The analyses were only done for these three seasons since they have the highest variability in dissolved oxygen concentrations.

Staff was also interested in whether the dissolved oxygen concentrations differ between stations along a particular water body depending upon whether the barrier was installed or not; however, it was too difficult to determine if differences were due to barrier operations or seasonality. Therefore, staff decided to do the seasonal differences analysis discussed above.

The 401 Water Quality Certification for the Temporary Barriers Project requires the statistical comparison of the dissolved oxygen concentrations measured upstream and downstream of the three temporary barriers on a monthly basis. For each barrier, staff used one the following nonparametric hypothesis tests to compare the upstream and downstream stations that are closest to the barrier:

- The 1-sample Wilcoxon test: This is the preferred test for this type of analysis since it is used to compare paired values, such as paired daily medians of the upstream and downstream stations. However, because this test requires data to be paired, it does not accommodate a data set with missing data.
- The Mann-Whitney test: This test is used to compare two non-paired or independent groups of data, and can be used with data sets with missing data.

None of the stations upstream or downstream of each of the temporary barriers had complete data records for dissolved oxygen, therefore, staff used the Mann-Whitney test to compare daily medians. For all of these two-station comparisons, staff performed these analyses separately for each month during 2012.

RESULTS

The results and analyses for the South Delta continuous monitoring data from 2012 are discussed below with a separate section for each constituent collected. The monthly maximums, minimums, averages, medians and standard deviations for each constituent are summarized in Table 5-3 for the Grant Line Canal stations, Table 5-4 for the Victoria Canal station, Table 5-5 for the Middle River stations, and Table 5-6 for the Old River stations.

Water Temperature

Temperature affects pH, conductance, the solubility of constituents such as dissolved oxygen, the rate of chemical reactions, and biological activity in water (Radtke et al., 2004). It is also probably the single most important factor affecting fish distribution both between and within estuaries seasonally, although temperature effects are closely tied to the effects of other variables (Moyle and Cech, 2000).

During 2012, the highest water temperature at the South Delta continuous monitoring stations was 30.6°C (87.1ºF) on August 14th at Middle River at Undine Road, and the lowest was 5.3°C (41.5ºF) on January 18th at Middle River at Howard Road (Tables 5-5). Figures 5-2, 5-3, and 5-4 illustrate the daily maximums, minimums, and averages for the Grant Line and Victoria Canal, Middle River, and Old River stations, respectively. Temperature patterns followed seasonal trends, with the highest temperatures occurring in summer and the lowest in winter. Monthly mean temperatures in the summer (June – August) ranged from 22.1 ºC (71.8ºF) in June at Doughty Cut above Grant Line Canal and Grant Line Canal at Tracy Blvd. to 25.7 ºC (78.3 ºF) at Old River at Head in August (Tables 5-3 to 5-6). In the winter (January – February, and December), monthly mean temperatures ranged from 8.4ºC (47.1ºF) in December at Middle River at Howard Road to 12ºC (50.7ºF) in February at Middle River at Undine Rd. Water temperatures in spring and fall exhibited the steepest increases and decreases in temperature in accordance with seasonal temperature changes. Yearly mean temperatures for the 2012 monitoring period ranged from 17.2°C (63.0 ºF) at Old River upstream the ORT barrier to 18.0°C (64.4ºF) at Old River at Tracy Wildlife Association.

Table 5-3: Monthly Statistics for the Grant Line Canal continuous water quality monitoring stations

	Water Temperature (°C)				Dissolved Oxygen (mg/L)				pH			
Month	Doughty Cut	GLC abv Barrier	GLC @ Tracy Blvd	GLC nr Old River	Doughty Cut	GLC abv Barrier	GLC @ Tracy Blvd	GLC nr Old River	Doughty Cut	GLC abv Barrier	GLC @ Tracy Blvd	GLC nr Old River
	MAXIMUMS				MAXIMUMS				MAXIMUMS			
January	11.9	11.8	11.9	11.8	12.75	12.67	12.28	11.92	8.15	8.32	8.09	8.13
February	14.3	14.4	14.1	13.7	11.11	11.03	10.68	10.18	8.15	8.09	7.94	7.94
March	17.1	17.0	16.8	16.6	16.33	14.94	15.07	12.49	8.92	8.84	8.65	8.45
April	23.2	22.9	22.7	22.3	14.69	14.08	13.94	10.38	8.85	8.96	8.86	8.06
May	22.7	22.7	22.1	22.5	13.30	10.08	9.10	9.02	8.62	8.16	7.77	7.92
June	26.8	26.9	25.9	25.7	16.36	15.98	14.30	10.03	9.44	9.68	9.36	8.50
July	28.3	28.3	26.5	26.8	16.32	18.99	10.10	10.16	9.60	9.61	9.07	8.77
August	28.7	29.6	28.0	27.7	12.73	15.09	8.66	8.33	9.10	9.39	8.92	7.98
September	25.2	25.8	24.7	25.4	13.98	14.21	11.39	8.59	9.07	9.15	8.53	7.92
October	24.9	24.6	24.3	24.0	11.84	12.36	10.22	8.94	8.49	8.75	8.13	7.85
November	17.6	17.7	17.6	18.1	11.14	11.18	11.01	10.03	8.15	8.17	7.99	8.06
December	14.3	14.1	14.2	14.2	11.27	10.90	10.97	11.03	7.98	7.91	7.91	7.95
	AVERAGES				AVERAGES				AVERAGES			
January	9.5	9.5	9.6	9.2	11.32	11.25	11.02	10.65	7.94	7.92	7.82	7.80
February	12.2	12.2	12.1	11.8	10.10	9.85	9.85	9.61	7.98	7.83	7.74	7.74
March	14.1	14.2	13.9	13.6	11.06	10.72	10.88	9.27	8.19	8.16	7.94	7.77
April	17.9	17.9	17.8	17.6	9.24	8.57	8.54	8.29	7.65	7.64	7.62	7.61
May	19.8	19.9	19.9	20.5	7.98	7.85	7.68	7.67	7.46	7.61	7.42	7.65
June	22.1	22.3	22.1	22.3	9.77	9.29	9.25	7.36	8.05	8.21	8.02	7.65
July	25.0	25.0	24.6	24.3	8.65	7.14	5.43	6.21	8.87	8.50	8.14	7.53
August	25.4	25.6	25.3	24.6	7.07	5.48	4.59	5.49	8.06	7.99	7.60	7.41
September	23.1	23.1	22.9	22.6	9.94	8.71	7.97	6.70	8.42	8.16	7.91	7.49
October	18.8	18.8	18.7	19.1	8.99	8.62	8.48	7.89	7.74	7.85	7.65	7.52
November	14.4	14.4	14.5	14.9	9.64	9.50	9.40	8.73	7.73	7.78	7.68	7.66
December	10.8	10.9	10.9	11.0	9.61	9.34	9.40	9.20	7.70	7.66	7.65	7.61
	MEDIANS				MEDIANS				MEDIANS			
January	9.3	9.4	9.4	9.1	11.36	11.27	11.06	10.64	7.95	7.94	7.83	7.83
February	12.0	12.0	12.0	11.6	10.12	9.88	9.90	9.62	7.98	7.81	7.78	7.76
March	14.2	14.2	14.1	13.5	10.82	10.47	10.54	9.38	8.19	8.16	8.14	7.75
April	16.8	16.7	16.7	16.4	9.48	8.64	8.72	8.52	7.81	7.74	7.68	7.63
May	19.8	19.9	19.9	20.8	7.74	7.70	7.56	7.71	7.48	7.64	7.42	7.66
June	21.8	21.9	21.8	22.3	9.51	9.00	9.16	7.40	8.35	8.52	8.45	7.67
July	25.1	25.1	24.8	24.4	8.65	7.00	5.15	6.43	8.96	8.81	8.41	7.53
August	25.4	25.5	25.3	24.4	7.03	5.08	4.26	5.33	8.31	8.09	7.85	7.39
September	23.0	23.0	22.9	22.5	9.95	8.59	7.97	6.72	8.45	8.22	7.97	7.50
October	18.5	18.6	18.4	19.1	9.04	8.63	8.56	8.02	7.80	7.87	7.69	7.55
November	14.0	14.1	14.2	14.5	9.64	9.48	9.40	8.78	7.72	7.77	7.70	7.67
December	10.1	10.1	10.0	10.5	9.56	9.28	9.35	9.21	7.72	7.69	7.68	7.61
	MINIMUMS				MINIMUMS				MINIMUMS			
January	7.3	7.6	7.6	7.6	9.74	9.51	7.93	9.00	7.69	7.61	7.61	7.46
February	10.7	11.1	11.0	10.1	7.82	8.56	7.65	8.89	7.86	7.67	7.44	7.47
March	11.1	11.3	11.2	11.3	8.91	7.99	8.11	7.08	7.82	7.79	7.54	7.50
April	14.4	14.5	14.3	14.3	4.08	3.93	2.64	4.25	7.06	7.06	7.09	7.19
May	17.7	17.9	18.0	18.3	5.33	5.86	5.52	6.23	7.18	7.33	7.15	7.37
June	18.8	19.6	19.7	19.3	6.73	5.21	4.65	5.40	7.35	7.59	7.30	7.30
July	21.5	21.6	21.6	22.0	1.89	1.47	1.23	2.33	7.85	7.47	7.23	7.15
August	22.9	22.8	23.0	22.2	1.63	0.75	1.43	2.30	6.88	7.43	6.54	7.12
September	21.3	21.4	21.5	21.1	5.40	1.14	4.24	4.06	7.94	7.64	7.46	7.28
October	14.6	14.7	14.6	15.2	5.41	6.29	5.10	5.97	7.26	7.50	7.24	7.24
November	12.2	12.2	12.3	12.5	6.23	7.95	7.94	7.69	7.47	7.58	7.27	7.26
December	8.0	8.2	8.2	8.3	7.85	7.45	7.67	7.04	7.48	7.45	7.46	7.33
	STANDARD DEVIATIONS				STANDARD DEVIATIONS				STANDARD DEVIATIONS			
January	1.1	1.1	1.1	1.0	0.55	0.56	0.56	0.52	0.08	0.15	0.12	0.15
February	0.7	0.7	0.7	0.7	0.38	0.40	0.36	0.24	0.06	0.09	0.10	0.09
March	1.3	1.3	1.4	1.2	1.21	1.23	1.28	0.87	0.22	0.23	0.31	0.19
April	2.3	2.3	2.3	2.5	2.53	2.36	2.36	1.26	0.49	0.51	0.49	0.14
May	1.0	0.9	0.9	1.0	0.84	0.71	0.63	0.44	0.21	0.16	0.13	0.11
June	1.7	1.6	1.5	1.4	1.53	1.86	1.58	0.69	0.51	0.54	0.54	0.19
July	1.3	1.2	1.0	0.9	1.96	2.51	1.88	1.41	0.24	0.41	0.42	0.26
August	1.2	1.3	1.1	1.1	1.73	2.23	1.50	1.62	0.42	0.42	0.46	0.18
September	0.8	0.8	0.7	0.8	1.11	1.82	1.03	1.15	0.18	0.30	0.22	0.12
October	2.5	2.5	2.5	2.2	0.70	0.79	0.64	0.56	0.27	0.24	0.18	0.14
November	1.7	1.7	1.7	1.6	0.58	0.53	0.53	0.39	0.13	0.10	0.09	0.11
December	2.1	2.0	2.1	2.0	0.83	0.79	0.80	0.91	0.12	0.11	0.12	0.15
2012 - Max.	28.7	29.6	28.0	27.7	16.36	18.99	15.07	12.49	9.60	9.68	9.36	8.77
2012 - Avg.	17.8	17.8	17.8	17.7	9.44	8.85	8.47	8.09	7.86	7.87	7.72	7.61
2012 - Med.	17.9	17.9	18.4	18.6	9.60	9.60	8.86	8.16	7.99	7.99	7.77	7.65
2012 - Min.	7.3	7.6	7.6	7.6	1.63	0.75	1.23	2.30	6.88	7.06	6.54	7.12
2012 - S.D.	5.5	5.5	5.5	5.4	1.75	2.13	2.24	1.73	0.48	0.45	0.41	0.19

Table 5-3 (continued): Monthly Statistics for the Grant Line Canal continuous water quality monitoring stations

Month	Specific Conductance (µS/cm)				Turbidity (NTU)				Chlorophyll (µg/L)			
	Doughty Cut	GLC abv Barrier	GLC @ Tracy Blvd	GLC nr Old River	Doughty Cut	GLC abv Barrier	GLC @ Tracy Blvd	GLC nr Old River	Doughty Cut	GLC abv Barrier	GLC @ Tracy Blvd	GLC nr Old River
	MAXIMUMS				MAXIMUMS				MAXIMUMS			
January	874	862	887	862	36.9	33.0	19.2	36.5	37.2	43.1	57.2	26.8
February	1102	1037	1028	1002	36.0	41.8	24.1	39.0	51.3	48.9	18.2	19.7
March	1110	1086	1077	1061	37.2	52.2	27.6	32.4	125.2	142.5	91.2	76.4
April	1062	1012	1010	1012	48.9	44.4	35.0	37.6	100.3	105.6	64.3	24.0
May	697	613	615	626	43.8	56.7	31.9	38.2	61.6	74.7	20.3	6.3
June	814	724	727	655	67.3	55.6	37.2	36.7	155.0	176.1	83.5	8.9
July	845	789	771	756	82.8	53.7	38.8	29.6	162.3	168.7	95.7	40.1
August	886	792	788	760	52.1	65.3	34.9	38.5	114.0	57.7	52.7	39.0
September	805	806	812	808	61.2	24.7	40.2	31.3	96.9	104.1	42.7	29.4
October	791	773	774	772	38.4	43.4	44.7	42.1	52.2	47.4	29.5	23.5
November	832	842	858	815	66.1	46.9	35.4	39.2	72.4	64.5	30.6	45.2
December	1015	941	943	931	141.4	185.2	183.8	100.3	29.9	30.5	22.3	39.6
	AVERAGES				AVERAGES				AVERAGES			
January	769	772	772	726	8.1	4.6	4.5	4.8	--	8.9	13.6	5.3
February	837	847	846	743	8.3	4.8	5.0	5.5	--	6.0	8.0	3.5
March	949	956	983	790	12.3	9.6	10.2	6.7	--	34.3	28.8	6.7
April	687	675	677	604	18.4	13.0	12.7	8.4	--	14.2	12.1	3.8
May	408	407	407	435	11.5	7.6	7.5	7.5	--	2.0	3.5	3.8
June	539	531	535	433	19.4	14.7	15.4	8.1	--	47.7	34.4	3.4
July	645	645	643	447	21.8	13.6	16.3	8.9	--	50.4	40.4	4.2
August	702	707	709	537	16.6	16.6	11.8	8.1	--	12.4	19.5	3.2
September	730	732	736	667	11.3	6.8	10.1	5.0	--	17.7	15.9	2.2
October	565	558	563	537	6.5	4.7	6.7	3.7	--	9.0	10.2	2.4
November	746	748	753	599	7.5	4.3	4.8	5.0	--	7.3	9.2	2.2
December	748	743	743	658	18.9	16.9	16.0	15.6	--	5.7	7.2	4.5
	MEDIANS				MEDIANS				MEDIANS			
January	780	777	775	744	7.9	4.2	4.3	4.3	16.3	8.4	12.6	4.9
February	812	826	825	758	8.1	4.2	4.9	5.4	7.3	5.2	7.2	2.9
March	952	968	984	865	11.9	9.0	10.1	6.2	40.2	31.1	19.9	5.1
April	613	587	588	562	17.8	12.8	12.5	8.2	22.1	4.4	6.7	3.8
May	407	408	405	422	11.7	7.0	7.6	7.2	3.9	1.7	3.0	3.8
June	540	516	520	418	20.1	15.3	16.9	7.6	62.9	39.5	33.0	3.4
July	672	686	681	425	21.0	13.0	16.2	8.4	83.8	45.5	39.0	2.9
August	702	705	705	598	16.1	14.4	11.6	7.5	42.8	9.8	17.7	3.0
September	729	732	735	710	10.2	6.7	9.7	4.4	36.3	15.6	14.7	2.0
October	576	575	576	501	6.2	4.2	6.0	2.9	10.6	6.7	9.1	2.1
November	752	749	754	645	6.4	3.9	4.3	3.8	9.7	5.2	8.2	2.0
December	781	778	781	687	9.2	6.5	6.5	9.2	5.8	4.0	6.4	3.3
	MINIMUMS				MINIMUMS				MINIMUMS			
January	637	648	646	515	4.3	1.6	1.8	2.2	9.0	2.8	3.7	0.8
February	679	681	678	500	4.8	1.8	1.8	2.0	1.7	1.5	3.0	1.3
March	797	796	825	445	6.7	3.9	4.3	2.5	2.2	2.5	4.0	1.3
April	515	510	512	435	10.6	5.8	5.9	2.4	2.8	1.3	1.8	1.2
May	231	236	239	306	4.3	2.0	2.6	3.9	0.2	0.5	0.7	1.1
June	415	412	425	286	7.5	2.2	2.9	3.8	2.2	0.9	2.0	1.4
July	417	420	418	238	12.4	4.1	5.9	2.7	27.1	5.6	7.9	0.6
August	606	625	646	261	6.8	3.2	3.4	2.7	12.9	1.4	5.5	1.0
September	656	673	688	358	3.6	2.1	3.4	2.0	5.2	2.5	4.4	1.0
October	278	275	288	282	2.1	0.0	1.9	1.4	0.5	1.6	2.0	0.6
November	537	542	543	373	3.1	1.8	2.0	1.5	3.7	1.4	3.0	0.8
December	389	389	389	299	4.5	1.6	1.3	1.9	1.7	1.9	2.7	1.6
	STANDARD DEVIATIONS				STANDARD DEVIATIONS				STANDARD DEVIATIONS			
January	56	54	55	92	2.4	2.0	1.6	2.1	4.1	3.0	4.1	1.8
February	89	85	86	126	2.7	2.9	1.2	1.8	2.7	3.0	2.7	1.5
March	62	63	46	197	3.0	3.4	3.4	2.4	17.1	22.2	20.3	6.6
April	160	169	170	146	3.8	3.1	2.9	3.0	27.0	18.6	12.2	1.5
May	102	94	95	78	3.3	3.9	2.7	2.4	4.1	2.4	1.8	0.8
June	86	77	78	113	6.2	6.5	6.6	2.5	33.0	37.3	21.3	0.8
July	87	94	92	158	5.5	4.6	3.7	3.6	24.7	27.3	16.6	4.5
August	39	29	29	162	4.2	8.3	3.0	3.2	20.2	8.3	8.2	1.4
September	31	26	25	104	4.7	2.2	3.2	2.3	13.3	10.7	6.7	1.1
October	150	156	151	137	2.3	3.0	3.8	3.2	8.8	7.0	4.2	1.4
November	43	50	51	152	4.1	2.3	2.4	3.5	4.1	6.0	4.6	1.6
December	156	156	155	178	22.9	25.6	24.1	17.1	4.1	4.4	3.2	3.0
2012 - Max.	1110	1086	1077	1061	141.4	185.2	183.8	100.3	162.3	176.1	95.7	76.4
2012 - Avg.	693	693	689	597	14.0	9.7	10.0	7.2	--	18.2	16.7	3.8
2012 - Med.	713	713	715	589	12.0	12.0	8.3	6.2	17.4	8.5	11.2	3.2
2012 - Min.	231	236	239	238	2.1	0.0	1.3	1.4	0.2	0.5	0.7	0.6
2012 - S.D.	169	172	170	184	9.5	9.9	8.9	5.7	29.4	23.1	15.5	3.1

Table 5-4: Monthly Statistics for the Victoria Canal water quality monitoring station

Month	Water Temperature (°C)	Dissolved Oxygen (mg/L)	pH	Specific Conductance (µS/cm)	Turbidity (NTU)	Chlorophyll (µg/L)
	MAXIMUMS					
January	10.1	10.98	7.79	602	23.6	13.6
February	12.9	10.28	7.69	600	24.1	35.1
March	15.4	10.65	7.77	592	22.2	39.8
April	21.8	10.71	8.02	653	29.0	25.7
May	22.8	9.31	7.86	542	14.8	17.8
June	25.4	9.04	8.13	384	26.9	6.5
July	26.0	11.23	9.23	399	31.1	42.6
August	25.7	8.83	7.97	366	31.0	18.2
September	24.2	9.36	7.92	459	31.0	16.3
October	22.9	8.97	7.97	432	7.4	16.7
November	18.2	9.49	7.74	416	36.7	22.1
December	14.1	10.67	7.83	508	36.0	8.2
	AVERAGES					
January	8.7	10.33	7.54	518	3.7	3.4
February	11.3	9.73	7.49	526	4.3	6.3
March	12.9	9.60	7.58	506	5.2	6.6
April	17.3	9.17	7.69	528	3.3	4.4
May	20.7	8.07	7.51	417	5.6	3.6
June	22.6	7.82	7.65	324	5.8	3.4
July	24.2	7.98	7.69	256	7.7	4.5
August	24.0	7.91	7.58	257	6.5	3.5
September	22.2	8.24	7.59	371	2.8	3.4
October	19.6	8.32	7.65	383	2.1	3.6
November	15.4	8.79	7.50	337	2.2	3.2
December	11.2	9.05	7.47	361	10.1	4.6
	MEDIANS					
January	8.6	10.32	7.56	525	3.2	3.2
February	11.4	9.75	7.52	524	4.0	5.7
March	12.9	9.53	7.63	502	5.0	6.0
April	16.3	9.30	7.68	529	3.1	4.2
May	21.0	8.05	7.52	430	5.2	3.6
June	22.6	7.80	7.74	321	5.5	3.4
July	24.2	7.76	7.68	247	7.0	2.8
August	24.1	7.90	7.58	250	6.1	3.3
September	22.1	8.23	7.60	370	2.2	3.3
October	19.6	8.35	7.63	384	1.8	3.4
November	14.7	8.82	7.49	334	1.6	3.1
December	11.1	8.76	7.48	361	9.8	4.6
	MINIMUMS					
January	7.7	9.72	7.28	427	1.1	1.5
February	9.8	9.09	7.30	484	1.2	2.4
March	11.1	8.93	7.37	462	1.8	3.7
April	13.8	7.01	7.46	461	1.4	2.3
May	18.4	6.73	7.22	318	3.1	2.1
June	19.9	6.69	7.15	291	2.6	1.9
July	22.6	6.37	7.13	203	1.2	0.7
August	22.1	7.02	7.29	216	1.8	1.9
September	20.8	7.21	7.33	289	0.5	2.0
October	17.3	7.06	7.41	337	1.0	2.0
November	13.4	7.86	7.25	302	0.7	1.4
December	8.0	7.74	7.17	266	1.6	3.1
	STANDARD DEVIATIONS					
January	0.6	0.22	0.12	38	2.0	1.1
February	0.7	0.20	0.10	23	1.8	2.3
March	0.9	0.35	0.10	21	1.9	2.5
April	2.5	0.81	0.11	33	1.5	1.5
May	1.1	0.41	0.12	62	1.4	0.6
June	1.2	0.40	0.19	17	1.6	0.5
July	0.7	0.89	0.46	31	3.4	4.7
August	0.7	0.35	0.13	24	2.7	1.3
September	0.7	0.41	0.10	49	2.4	0.9
October	1.5	0.28	0.13	21	1.0	1.0
November	1.5	0.32	0.11	23	2.3	1.0
December	2.0	0.92	0.17	55	5.4	0.5
2012 - Max.	26.0	11.23	9.23	653	36.7	42.6
2012 - Avg.	17.5	8.75	7.57	398	5.3	4.2
2012 - Med.	18.9	8.52	7.60	383	4.6	3.6
2012 - Min.	7.7	6.37	7.13	203	0.5	0.7
2012 - S.D.	5.4	0.95	0.21	103	3.4	2.3

Table 5-5: Monthly Statistics for the Middle River continuous water quality monitoring stations

	Water Temperature (°C)				Dissolved Oxygen (mg/L)				pH			
Month	Undine	Howard	Tracy Blvd	Union Point	Undine	Howard	Tracy Blvd	Union Point	Undine	Howard	Tracy Blvd	Union Point
	MAXIMUMS				MAXIMUMS				MAXIMUMS			
January	12.7	11.7	11.0	10.4	16.07	14.31	11.59	11.15	8.76	8.14	7.88	7.79
February	15.6	14.4	13.7	12.9	13.86	12.75	10.88	10.55	8.58	8.34	7.99	7.80
March	18.2	17.3	17.1	16.2	19.32	16.50	11.47	10.65	9.09	8.94	8.12	7.89
April	17.8	25.3	25.0	21.9	13.62	16.57	11.57	10.66	8.71	8.66	8.48	8.14
May	24.9	24.8	24.4	22.8	15.86	10.96	10.28	9.25	9.31	8.48	8.31	7.98
June	28.2	27.8	26.5	25.0	15.62	11.21	9.29	9.19	9.46	8.79	8.00	8.04
July	28.9	28.3	27.5	26.4	17.47	13.99	10.18	11.93	9.59	9.13	8.60	9.21
August	30.6	27.7	27.0	25.9	17.10	7.43	7.86	9.40	9.39	7.45	7.61	8.36
September	26.2	24.0	24.7	24.4	16.87	6.77	8.07	9.65	9.21	7.58	7.50	8.14
October	25.4	23.4	23.5	22.9	14.99	8.95	8.68	9.01	8.92	7.81	7.67	7.83
November	18.7	16.9	18.3	18.3	15.60	10.20	10.24	9.63	8.84	8.33	7.73	7.71
December	14.8	13.8	14.3	14.1	12.29	10.75	10.53	10.68	8.14	7.67	7.65	7.52
	AVERAGES				AVERAGES				AVERAGES			
January	9.4	8.4	8.5	8.7	11.72	11.44	10.54	10.28	8.01	7.47	7.63	7.57
February	12.0	11.7	11.3	11.3	10.41	10.41	9.86	9.54	7.93	7.88	7.68	7.48
March	14.1	13.8	13.3	13.0	10.48	9.53	9.01	9.34	8.02	7.69	7.64	7.69
April	15.8	18.6	17.8	17.3	9.77	9.22	8.89	9.00	8.02	7.87	7.65	7.81
May	19.7	21.0	20.7	20.9	10.17	6.81	7.77	7.88	7.91	7.44	7.60	7.55
June	22.2	23.1	22.4	22.5	10.49	5.20	6.72	7.74	8.38	7.26	7.47	7.58
July	25.0	24.9	24.2	24.2	9.89	4.00	6.04	7.94	8.96	7.08	7.41	7.79
August	25.5	24.9	24.0	23.9	8.36	2.36	5.28	7.92	8.32	6.86	7.21	7.65
September	22.9	22.2	22.1	22.1	10.05	2.83	5.57	8.03	8.39	6.94	7.07	7.65
October	18.5	18.6	19.0	19.6	9.56	5.31	5.15	8.10	7.91	7.12	7.12	7.50
November	14.3	13.4	14.8	15.4	11.15	7.08	8.42	8.61	8.07	7.22	7.35	7.53
December	10.6	10.6	10.7	11.2	9.21	7.02	8.76	8.94	7.68	7.18	7.31	7.27
	MEDIANS				MEDIANS				MEDIANS			
January	9.1	8.4	8.4	8.6	11.40	11.43	10.54	10.23	8.03	7.56	7.63	7.57
February	12.0	11.6	11.3	11.4	10.29	10.59	9.83	9.53	7.93	7.96	7.67	7.45
March	14.2	13.8	13.2	12.9	10.19	9.08	8.92	9.27	8.02	7.67	7.67	7.70
April	15.5	17.5	17.0	16.2	9.62	9.17	8.90	9.09	8.04	7.88	7.64	7.81
May	19.7	21.2	20.7	21.0	10.09	6.75	7.74	7.84	8.26	7.74	7.60	7.56
June	22.0	23.0	22.3	22.5	10.45	5.12	6.71	7.75	8.85	7.34	7.48	7.56
July	24.9	24.8	24.2	24.1	9.86	3.73	5.99	7.76	9.10	7.10	7.40	7.77
August	25.5	24.9	24.0	23.9	8.23	2.14	5.49	7.90	8.65	6.85	7.23	7.76
September	22.9	22.1	22.0	22.0	9.66	2.65	5.61	8.06	8.53	6.92	7.09	7.69
October	18.2	18.6	19.0	19.6	9.30	5.55	5.28	8.15	7.97	7.13	7.16	7.51
November	13.7	12.8	14.3	14.7	10.92	7.10	8.65	8.71	8.14	7.44	7.35	7.54
December	9.6	10.8	10.3	11.1	9.52	6.79	8.85	8.74	7.72	7.22	7.31	7.29
	MINIMUMS				MINIMUMS				MINIMUMS			
January	6.3	5.3	6.2	7.3	8.19	9.43	9.13	9.40	7.51	7.09	7.45	7.36
February	9.2	9.1	9.5	9.8	7.45	6.10	8.05	8.59	7.60	7.24	7.53	7.28
March	10.3	9.7	10.1	10.8	5.16	5.93	7.21	8.42	7.63	7.36	7.29	7.52
April	14.6	14.3	13.6	13.7	7.08	3.73	6.11	7.07	7.77	7.48	7.31	7.63
May	16.5	17.4	17.9	18.8	4.95	0.46	5.46	6.63	7.34	6.69	7.27	7.19
June	17.6	18.8	19.1	20.0	4.26	0.38	2.52	6.51	7.30	6.64	7.12	7.36
July	20.0	22.1	21.9	22.4	0.53	0.24	3.67	3.12	7.80	6.71	7.00	7.36
August	21.6	21.5	21.4	22.0	0.85	0.23	0.84	5.38	7.21	6.68	6.90	7.22
September	20.1	18.9	20.3	20.9	0.39	0.39	1.77	5.68	7.39	6.73	6.78	7.26
October	13.9	15.2	15.8	17.0	1.16	1.33	1.47	5.52	7.33	6.82	6.81	7.10
November	11.3	11.2	12.6	13.2	7.43	4.77	5.32	6.98	7.62	6.80	7.19	7.25
December	7.0	7.2	7.3	8.1	4.45	4.45	6.36	7.43	7.30	6.82	7.05	7.07
	STANDARD DEVIATIONS				STANDARD DEVIATIONS				STANDARD DEVIATIONS			
January	1.3	1.4	0.9	0.6	1.63	0.96	0.39	0.29	0.27	0.25	0.07	0.08
February	1.0	1.1	0.9	0.7	1.37	1.28	0.40	0.32	0.21	0.20	0.09	0.13
March	1.5	1.6	1.4	1.0	1.73	1.82	0.75	0.37	0.27	0.32	0.15	0.06
April	0.9	3.0	2.7	2.4	1.12	2.75	1.01	0.70	0.18	0.25	0.18	0.08
May	2.0	1.5	1.3	0.9	2.91	1.60	0.71	0.43	0.64	0.37	0.15	0.19
June	2.1	1.9	1.4	1.1	2.25	1.97	0.79	0.45	0.48	0.32	0.12	0.13
July	1.8	1.3	1.0	0.7	2.79	1.89	0.95	1.03	0.27	0.29	0.18	0.39
August	1.8	1.2	1.0	0.6	2.90	1.33	1.24	0.45	0.45	0.09	0.13	0.24
September	1.3	0.8	0.8	0.7	2.82	1.24	1.10	0.43	0.34	0.15	0.13	0.12
October	2.5	2.1	1.8	1.5	1.91	1.71	1.56	0.38	0.39	0.22	0.16	0.12
November	1.9	1.8	1.7	1.5	1.47	1.01	0.99	0.40	0.28	0.33	0.10	0.08
December	2.2	2.0	2.2	2.0	1.74	1.40	0.91	0.88	0.19	0.14	0.13	0.12
2012 - Max.	30.6	28.3	27.5	26.4	19.32	16.57	11.59	11.93	9.59	9.13	8.60	9.21
2012 - Avg.	17.5	17.7	17.4	17.5	10.13	6.75	7.66	8.61	8.05	7.23	7.37	7.56
2012 - Med.	16.9	18.6	18.2	19.0	10.08	6.68	7.86	8.41	8.21	7.37	7.46	7.60
2012 - Min.	6.3	5.3	6.2	7.3	0.39	0.23	0.84	3.12	7.21	6.64	6.78	7.07
2012 - S.D.	6.0	5.8	5.5	5.4	2.34	3.29	2.03	0.96	0.51	0.43	0.25	0.23

Table 5-5 (continued): Monthly Statistics for the Middle River continuous water quality monitoring stations

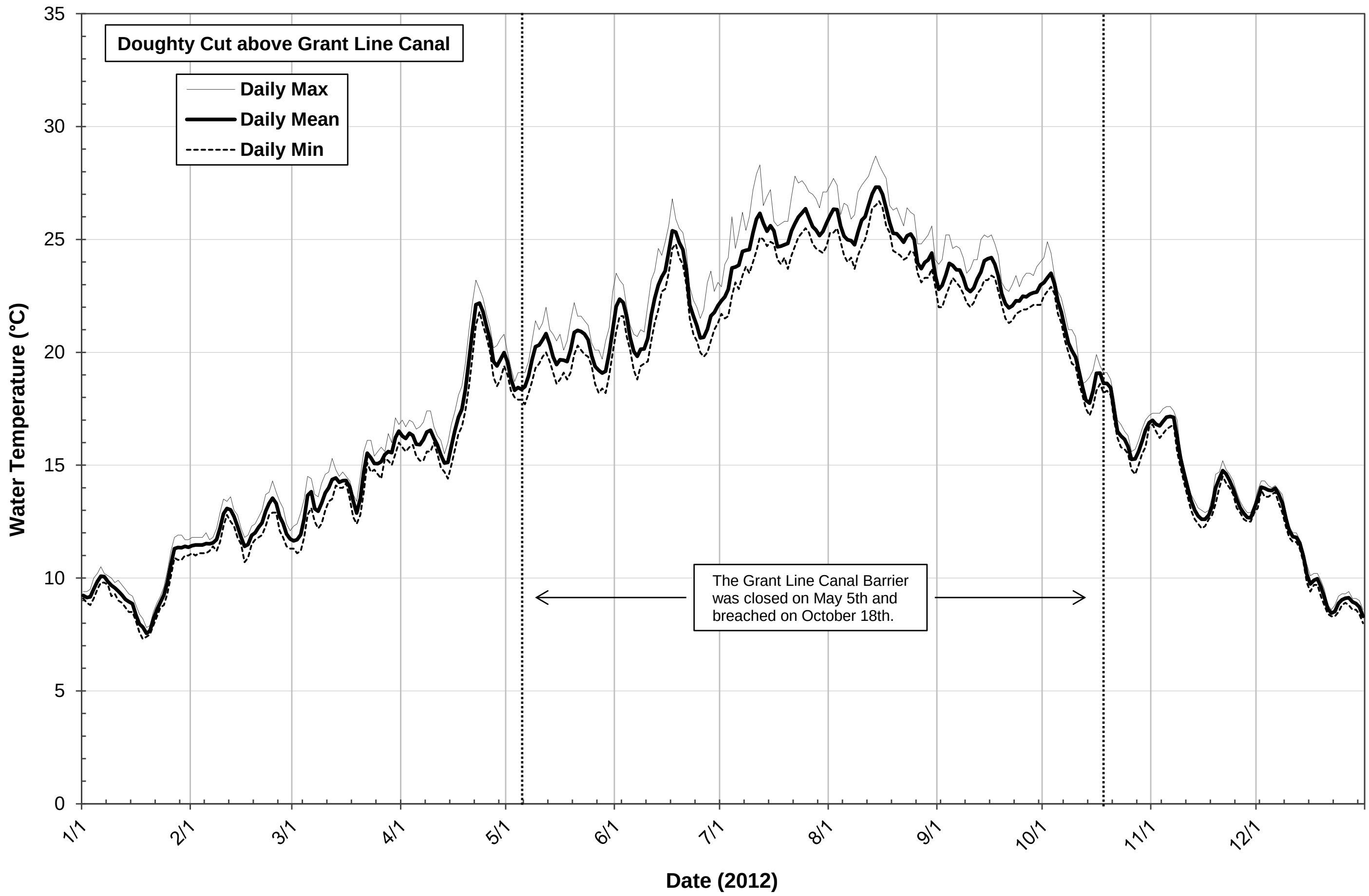
	Specific Conductance (µS/cm)				Turbidity (NTU)				Chlorophyll (µg/L)			
Month	Undine	Howard	Tracy Blvd	Union Point	Undine	Howard	Tracy Blvd	Union Point	Undine	Howard	Tracy Blvd	Union Point
	MAXIMUMS				MAXIMUMS				MAXIMUMS			
January	842	1266	919	689	29.7	15.8	61.8	37.6	72.7	15.0	22.0	20.9
February	1036	1194	931	655	38.3	35.6	33.3	45.2	59.3	8.6	16.1	24.4
March	1291	1524	1173	743	44.9	21.7	34.3	25.4	120.7	67.5	6.9	20.6
April	1128	1580	1217	734	23.4	38.4	35.5	41.1	54.9	16.1	9.5	17.9
May	453	1723	600	505	37.1	26.7	77.5	32.1	42.6	16.1	19.8	13.4
June	639	1071	410	363	66.0	37.0	46.1	21.5	112.2	9.1	60.4	10.2
July	733	1089	404	358	71.7	36.4	60.6	42.9	196.4	46.4	34.0	54.6
August	747	909	346	297	66.1	23.7	39.7	32.4	128.4	32.3	12.6	13.7
September	773	1133	489	434	35.8	38.7	33.6	29.8	113.9	32.8	33.4	13.4
October	767	982	751	501	28.3	37.7	49.5	35.6	53.9	27.8	37.1	13.8
November	807	1013	627	466	36.8	26.2	44.0	15.8	74.3	29.6	16.9	14.7
December	1230	1381	1094	807	533.8	67.2	223.0	111.5	41.0	12.0	4.6	12.3
	AVERAGES				AVERAGES				AVERAGES			
January	756	794	588	519	3.7	3.7	6.4	4.8	14.9	4.5	3.3	4.7
February	834	883	629	524	3.4	3.0	6.8	5.8	9.1	3.2	3.0	6.1
March	940	928	653	485	7.6	5.5	7.6	5.5	33.3	13.7	3.2	4.8
April	976	1080	655	511	6.7	4.0	4.9	4.6	18.8	3.7	3.2	5.1
May	389	597	431	398	5.8	4.3	7.3	6.3	4.7	4.4	3.1	4.1
June	502	505	345	312	20.6	4.9	9.4	5.4	52.9	3.5	4.0	3.2
July	618	463	286	240	26.2	6.5	12.2	7.5	84.8	7.3	3.6	6.0
August	674	450	281	242	17.4	4.2	7.4	4.6	41.1	5.7	3.1	2.9
September	703	623	384	366	10.7	5.0	5.2	3.0	33.1	4.8	2.5	2.9
October	541	618	511	378	3.8	5.1	5.8	2.5	16.4	3.1	2.7	2.6
November	732	669	427	337	2.7	2.4	3.4	2.0	14.2	2.3	2.7	2.9
December	766	901	575	354	32.7	7.9	18.2	11.2	11.2	3.0	2.7	3.2
	MEDIANS				MEDIANS				MEDIANS			
January	758	820	555	524	3.4	3.6	4.8	3.7	13.9	4.1	3.1	4.5
February	818	876	594	514	2.9	2.5	6.2	5.0	8.1	2.7	2.9	6.0
March	943	974	562	479	6.8	5.3	7.2	4.7	30.3	8.9	3.0	4.3
April	955	1074	609	502	5.5	2.3	4.3	3.8	13.7	3.6	3.2	4.9
May	384	582	448	407	5.1	3.8	6.2	5.7	4.4	4.3	2.9	3.9
June	489	486	340	309	21.1	4.2	8.3	5.1	57.6	3.4	3.3	3.2
July	642	448	269	229	24.9	5.3	10.2	7.0	76.9	5.8	3.0	3.4
August	677	411	280	234	15.5	3.6	7.2	4.2	32.7	5.0	3.0	2.8
September	703	601	372	371	9.8	3.5	4.8	2.6	33.9	4.4	2.4	2.9
October	565	607	461	376	2.9	3.4	4.7	2.0	12.1	2.2	2.6	2.5
November	727	718	417	332	2.3	2.0	2.4	1.8	13.1	2.3	2.6	2.8
December	767	950	544	344	6.5	3.1	10.8	10.4	8.5	2.1	2.7	3.0
	MINIMUMS				MINIMUMS				MINIMUMS			
January	647	518	432	422	1.6	1.2	1.8	1.1	2.4	0.0	2.2	2.3
February	646	674	471	475	1.2	1.4	1.9	1.2	3.6	1.1	1.8	3.7
March	767	546	441	445	1.1	1.2	2.8	2.0	4.0	2.9	2.3	2.7
April	920	757	474	454	2.6	0.6	1.7	1.6	5.4	1.3	2.3	3.2
May	343	411	338	309	2.6	0.6	2.6	2.3	2.0	1.4	2.1	1.6
June	356	387	299	280	2.8	0.5	4.1	2.6	2.8	1.1	2.2	1.7
July	399	304	218	194	5.3	1.2	3.1	1.8	9.9	3.3	1.6	2.0
August	572	303	224	203	3.2	0.9	2.1	1.3	6.3	2.7	1.7	1.1
September	644	437	296	289	2.1	0.9	1.9	0.9	5.0	2.2	1.8	1.2
October	290	357	388	333	1.2	0.7	1.6	0.7	3.8	0.2	2.1	0.9
November	509	385	312	300	1.2	0.7	1.2	0.7	5.4	0.2	2.1	0.9
December	339	515	301	260	2.1	1.3	3.6	2.3	4.4	1.1	1.9	0.8
	STANDARD DEVIATIONS				STANDARD DEVIATIONS				STANDARD DEVIATIONS			
January	53	133	107	45	1.8	1.6	5.6	3.3	5.9	2.1	1.0	1.3
February	89	72	111	34	2.3	1.9	3.1	3.4	3.7	1.2	0.5	1.6
March	66	217	181	32	4.2	2.6	2.8	2.5	20.1	10.7	0.6	1.4
April	48	178	137	39	3.3	4.6	2.6	2.7	12.0	1.0	0.4	1.2
May	26	105	58	62	3.3	2.1	4.3	2.1	2.7	0.9	1.0	1.1
June	76	81	24	17	9.7	3.1	4.1	1.5	22.4	1.0	3.6	0.6
July	74	118	44	36	9.0	4.0	6.7	3.5	42.9	4.7	2.6	6.6
August	32	116	20	24	8.7	2.4	2.6	2.2	25.7	2.7	0.9	0.8
September	30	129	48	50	4.8	4.3	2.0	1.7	12.5	2.0	0.8	0.8
October	152	114	99	24	2.6	4.0	4.0	2.5	10.5	2.4	0.7	0.8
November	47	131	69	27	1.8	1.8	3.9	1.1	6.0	1.2	0.5	0.9
December	201	171	180	66	59.2	11.1	21.4	8.9	6.2	2.1	0.4	1.0
2012 - Max.	1291	1723	1217	807	533.8	67.2	223.0	111.5	196.4	67.5	60.4	54.6
2012 - Avg.	699	705	480	388	13.0	4.7	7.9	5.4	30.5	5.0	3.1	4.0
2012 - Med.	706	667	456	375	5.7	3.4	6.2	4.5	18.0	4.1	2.9	3.4
2012 - Min.	290	303	218	194	1.1	0.5	1.2	0.7	2.0	0.0	1.6	0.8
2012 - S.D.	165	238	170	105	22.6	4.4	8.4	4.2	29.8	4.8	1.5	2.5

Table 5-6: Monthly Statistics for the Old River continuous water quality monitoring stations

Month	Water Temperature (°C)				Dissolved Oxygen (mg/L)				pH			
	Head	TWA	u/s ORT	d/s ORT	Head	TWA	u/s ORT	d/s ORT	Head	TWA	u/s ORT	d/s ORT
	MAXIMUMS				MAXIMUMS				MAXIMUMS			
January	11.9	11.5	11.4	11.5	12.16	13.75	12.89	12.71	8.18	8.13	8.46	8.52
February	14.0	14.2	14.1	13.9	11.36	10.74	11.10	11.49	8.30	8.05	8.20	8.25
March	17.5	16.8	16.7	16.5	14.72	15.95	15.11	15.41	8.82	8.89	8.87	9.13
April	20.5	24.8	21.9	22.0	13.73	23.84	9.66	9.78	8.78	9.38	8.06	8.26
May	22.1	24.3	22.7	22.6	11.61	11.62	9.33	8.87	8.58	8.69	8.17	8.02
June	26.3	27.9	24.7	24.9	14.74	16.78	11.01	11.20	9.75	9.11	9.07	9.14
July	28.6	28.7	26.8	26.0	19.49	20.53	16.73	11.04	9.89	9.68	9.54	9.16
August	29.3	27.9	26.9	26.9	16.80	10.54	16.74	10.26	9.62	8.87	9.11	8.58
September	26.2	25.4	23.6	23.4	15.45	11.33	8.04	8.48	9.03	8.40	7.67	7.94
October	24.4	24.4	22.4	22.6	14.51	9.65	8.22	8.61	8.75	8.26	7.56	7.80
November	18.0	18.3	18.1	18.1	11.12	10.38	9.15	9.49	8.04	7.86	7.65	7.72
December	14.3	14.3	14.1	14.0	10.78	10.33	10.47	10.81	7.90	7.82	7.74	7.89
	AVERAGES				AVERAGES				AVERAGES			
January	9.5	9.1	9.0	9.1	10.94	11.14	10.47	10.45	7.95	7.75	7.85	7.96
February	12.2	12.1	11.7	11.7	10.30	9.30	9.47	9.71	8.13	7.79	7.85	7.72
March	14.3	14.0	13.5	13.4	11.09	11.25	8.93	9.66	8.03	8.21	7.83	7.95
April	16.9	18.4	17.6	17.7	10.53	10.18	7.41	7.89	8.10	8.09	7.60	7.61
May	19.1	20.9	20.1	20.3	9.00	6.49	7.08	7.56	7.76	7.61	7.61	7.66
June	21.9	22.6	21.7	21.8	11.71	8.15	7.06	7.41	8.59	7.82	7.67	7.66
July	25.1	24.8	23.3	23.5	12.13	7.34	5.76	6.47	9.05	8.50	7.86	7.91
August	25.7	25.2	23.5	23.7	10.42	5.11	4.42	4.86	8.45	7.79	7.48	7.56
September	23.0	22.8	21.6	21.6	11.25	6.94	3.83	4.50	8.49	7.78	7.31	7.43
October	18.4	19.3	18.9	19.0	9.43	6.45	4.60	5.49	7.83	7.48	7.18	7.37
November	14.3	14.3	14.9	14.8	9.78	7.95	7.16	7.86	7.69	7.56	7.36	7.39
December	10.8	10.7	11.1	11.0	9.54	7.53	7.43	8.03	7.66	7.47	7.33	7.40
	MEDIANS				MEDIANS				MEDIANS			
January	9.4	8.9	8.8	8.8	10.96	11.06	10.37	10.30	7.95	7.78	7.88	8.00
February	12.0	11.9	11.7	11.6	10.31	9.31	9.45	9.67	8.12	7.76	7.86	7.74
March	14.4	14.1	13.5	13.4	10.79	11.00	8.94	9.65	8.08	8.24	7.85	7.97
April	16.6	17.4	16.4	16.4	10.34	9.47	7.96	8.30	8.17	8.37	7.71	7.58
May	19.1	20.9	20.2	20.5	8.94	6.73	7.24	7.58	7.75	7.68	7.66	7.69
June	21.7	22.4	21.7	21.8	11.62	7.88	7.05	7.38	8.69	7.89	7.69	7.64
July	25.2	24.9	23.2	23.5	12.52	7.25	5.75	6.52	9.27	8.63	8.00	7.99
August	25.6	25.1	23.3	23.5	10.68	4.85	4.14	4.62	8.88	7.80	7.50	7.58
September	22.9	22.8	21.5	21.5	11.20	6.86	3.59	4.10	8.56	7.77	7.31	7.42
October	18.0	19.1	18.7	18.8	9.34	6.77	4.18	5.11	7.86	7.56	7.16	7.37
November	13.9	13.6	14.3	14.3	9.80	8.11	7.28	8.16	7.69	7.59	7.37	7.41
December	10.1	10.2	10.8	10.8	9.56	8.01	7.54	8.15	7.69	7.50	7.35	7.42
	MINIMUMS				MINIMUMS				MINIMUMS			
January	7.3	6.9	7.2	7.2	9.67	9.00	7.94	9.43	7.82	7.48	7.52	7.68
February	10.9	10.4	10.1	10.0	8.58	8.03	5.93	8.93	7.96	7.47	7.61	7.43
March	11.0	10.7	10.7	11.2	8.70	4.21	1.24	7.50	7.67	7.63	7.34	7.54
April	14.2	15.0	14.5	14.4	7.89	0.66	0.75	4.70	7.53	7.46	7.18	7.26
May	17.4	18.2	18.0	18.3	5.76	0.76	0.79	6.33	7.41	7.11	7.12	7.31
June	18.7	19.3	18.6	18.6	4.33	0.79	2.49	5.47	7.86	7.23	7.15	7.27
July	21.2	21.4	21.1	21.2	3.80	0.94	1.42	2.32	7.52	7.69	7.25	7.34
August	22.8	22.3	20.9	21.2	3.93	0.95	1.05	1.79	7.49	7.41	7.17	7.22
September	20.9	21.2	19.7	19.9	5.78	4.50	0.84	1.74	7.58	7.44	7.10	7.18
October	14.4	15.5	15.7	15.5	1.69	2.68	1.03	1.63	7.37	7.03	6.96	7.11
November	12.0	12.2	12.6	12.7	7.74	4.66	3.18	4.87	7.41	7.22	7.07	7.05
December	7.8	8.0	8.2	8.3	8.01	1.27	3.19	3.85	7.47	7.10	7.07	7.11
	STANDARD DEVIATIONS				STANDARD DEVIATIONS				STANDARD DEVIATIONS			
January	1.1	1.1	0.9	1.0	0.46	0.72	0.67	0.63	0.06	0.11	0.17	0.19
February	0.7	0.9	0.8	0.7	0.35	0.41	0.38	0.34	0.05	0.12	0.12	0.16
March	1.4	1.3	1.2	1.1	1.25	1.57	1.37	1.05	0.28	0.26	0.24	0.28
April	1.8	2.6	2.3	2.4	1.27	5.01	1.52	1.08	0.28	0.53	0.21	0.24
May	0.9	1.2	1.0	1.0	0.69	1.69	1.01	0.47	0.21	0.24	0.19	0.13
June	1.7	1.8	1.4	1.3	1.11	2.95	0.93	0.83	0.54	0.51	0.30	0.33
July	1.3	1.2	0.9	0.9	2.57	2.44	1.94	1.68	0.31	0.30	0.45	0.45
August	1.3	1.2	1.2	1.2	2.78	1.44	1.80	1.69	0.48	0.31	0.30	0.25
September	0.8	0.7	0.7	0.7	1.38	0.98	1.41	1.61	0.19	0.16	0.11	0.14
October	2.5	2.3	1.7	1.7	0.95	1.23	1.71	1.83	0.29	0.24	0.10	0.16
November	1.7	1.6	1.6	1.6	0.47	0.98	1.12	1.08	0.08	0.10	0.11	0.11
December	2.0	2.1	2.0	2.0	0.62	1.77	1.61	1.57	0.11	0.15	0.16	0.18
2012 - Max.	29.3	28.7	26.9	26.9	19.49	23.84	16.74	15.41	9.89	9.68	9.54	9.16
2012 - Avg.	17.6	18.0	17.2	17.6	10.51	8.14	6.96	7.40	8.00	7.74	7.51	7.58
2012 - Med.	17.4	18.9	18.4	18.7	10.32	7.86	7.20	7.67	8.09	7.78	7.61	7.62
2012 - Min.	7.3	6.9	7.2	7.2	1.69	0.66	0.75	1.63	7.37	7.03	6.96	7.05
2012 - S.D.	5.5	5.7	5.1	5.0	1.67	2.85	2.39	2.18	0.56	0.45	0.35	0.34

Table 5-6 (continued): Monthly Statistics for the Old River continuous water quality monitoring stations

	Specific Conductance (µS/cm)				Turbidity (NTU)				Chlorophyll (µg/L)			
Month	Head	TWA	u/s ORT	d/s ORT	Head	TWA	u/s ORT	d/s ORT	Head	TWA	u/s ORT	d/s ORT
	MAXIMUMS				MAXIMUMS				MAXIMUMS			
January	843	1067	1151	1160	29.0	21.6	43.5	22.7	18.7	89.4	48.3	81.4
February	1047	1279	1297	1304	35.6	19.0	54.8	27.2	20.9	35.2	24.5	62.9
March	1056	1334	1581	1594	41.5	32.2	48.6	70.1	93.3	124.9	36.7	172.6
April	996	1440	1036	1045	44.1	61.9	40.3	34.7	45.8	300.2	14.2	49.3
May	520	1253	742	687	56.3	39.0	35.4	20.6	36.5	45.8	17.1	17.0
June	629	853	817	833	62.9	42.0	34.6	16.8	86.5	166.9	32.2	70.6
July	737	908	888	895	58.4	67.2	46.0	29.0	181.7	335.6	91.0	258.8
August	742	1002	948	923	54.9	45.5	46.0	39.8	118.4	181.3	74.8	241.9
September	770	979	998	995	44.3	30.2	47.3	40.8	68.7	118.4	11.1	24.8
October	777	899	980	985	20.9	26.6	49.1	44.4	44.5	36.9	6.2	15.0
November	815	1069	1105	1128	32.1	28.1	71.3	36.9	42.1	59.1	9.6	19.4
December	921	1159	1277	1280	311.5	117.5	80.3	71.9	31.8	69.1	19.4	21.0
	AVERAGES				AVERAGES				AVERAGES			
January	753	902	811	796	5.4	10.4	6.3	6.0	8.8	34.1	7.8	7.7
February	845	988	825	814	6.4	8.6	6.7	6.3	7.0	12.1	4.1	4.4
March	939	1129	883	866	10.5	14.1	8.0	8.3	32.1	37.2	7.1	10.3
April	549	1302	639	631	14.0	18.9	7.7	7.2	20.5	116.3	3.6	3.0
May	330	638	455	448	14.0	11.6	7.7	4.8	8.9	10.4	4.8	2.9
June	493	676	434	424	15.2	14.2	5.3	5.8	54.8	48.1	3.9	3.8
July	615	715	629	594	19.7	21.0	11.1	10.5	81.1	142.3	23.6	37.4
August	665	774	736	686	14.2	15.7	10.6	9.0	49.8	54.4	12.3	15.3
September	699	813	879	848	8.2	11.0	7.1	5.6	39.0	29.0	4.3	2.4
October	525	692	744	715	5.2	9.3	5.7	5.5	13.1	9.9	2.8	1.9
November	751	854	710	681	4.8	9.1	6.7	6.9	11.2	23.0	3.2	1.8
December	725	899	827	799	24.6	16.7	8.5	9.9	8.8	11.3	4.1	3.0
	MEDIANS				MEDIANS				MEDIANS			
January	757	916	803	766	5.1	9.1	5.1	5.5	8.4	31.4	5.4	3.7
February	853	954	812	801	6.0	7.2	5.7	6.1	5.0	11.1	3.7	3.9
March	951	1123	898	883	9.8	13.2	6.8	7.8	30.8	38.1	6.1	6.1
April	466	1300	573	572	13.0	17.9	6.9	6.9	19.3	120.8	3.3	2.9
May	342	551	463	453	13.1	10.6	5.9	4.7	7.2	8.8	4.8	2.9
June	486	681	407	385	14.5	13.1	4.7	5.9	54.7	22.2	3.4	1.8
July	635	746	644	610	18.8	20.7	10.3	10.0	71.9	126.1	17.9	19.1
August	669	766	806	754	13.6	15.4	9.9	8.2	50.2	47.7	6.8	4.3
September	696	812	912	899	8.1	10.1	6.5	5.0	39.4	19.9	4.0	2.1
October	540	703	795	759	4.8	9.2	4.3	4.1	9.7	9.4	2.7	1.8
November	752	851	691	602	4.3	9.1	4.7	5.4	9.9	20.7	3.2	1.8
December	764	919	890	862	8.6	11.3	5.6	6.7	6.9	10.0	3.7	2.4
	MINIMUMS				MINIMUMS				MINIMUMS			
January	626	737	522	560	2.5	4.8	2.3	2.3	3.4	12.4	1.1	1.1
February	553	791	492	492	2.9	3.8	2.6	2.1	2.5	1.8	0.9	0.8
March	763	936	463	455	3.7	6.3	3.2	1.8	8.6	4.7	0.4	1.7
April	384	996	462	453	5.4	5.2	3.1	3.0	2.5	9.4	1.3	1.0
May	187	331	313	309	6.5	5.1	2.3	1.8	1.7	1.8	2.4	0.8
June	390	478	293	292	5.5	3.4	1.8	2.1	25.1	3.1	1.3	0.7
July	382	454	254	254	7.9	11.1	3.4	3.9	18.1	33.4	3.9	1.6
August	539	669	302	292	4.4	8.2	2.8	2.9	8.0	9.0	1.7	1.3
September	608	722	500	451	1.9	3.9	1.6	2.1	8.6	3.9	1.6	0.8
October	258	392	383	331	1.8	3.1	1.0	1.5	2.7	1.8	0.9	0.3
November	617	597	384	372	1.4	3.6	1.7	1.3	2.4	4.5	1.1	0.6
December	335	540	330	308	2.1	1.7	1.8	1.9	3.8	3.1	1.7	1.0
	STANDARD DEVIATIONS				STANDARD DEVIATIONS				STANDARD DEVIATIONS			
January	53	60	163	160	1.6	3.9	4.2	2.5	2.2	13.2	6.9	12.6
February	97	129	182	187	2.2	3.3	4.1	2.0	4.1	3.7	1.9	2.8
March	63	98	267	279	4.1	3.3	4.6	4.1	11.6	19.8	4.3	15.4
April	172	67	127	125	5.1	5.7	3.3	1.9	6.6	78.0	1.2	1.4
May	72	247	84	79	4.8	3.7	4.2	1.1	5.5	6.1	1.2	0.9
June	71	93	118	122	4.7	6.8	2.5	1.7	9.7	45.8	2.7	8.0
July	73	95	171	178	5.2	3.9	4.1	3.3	37.1	54.1	17.4	43.5
August	39	42	170	184	4.3	3.3	4.3	3.4	23.6	27.8	11.6	30.5
September	33	35	101	120	2.9	3.3	3.5	2.3	9.0	22.5	1.3	1.4
October	148	116	174	180	2.2	2.2	5.4	4.8	8.3	3.8	0.6	0.7
November	38	78	239	246	2.4	1.7	6.8	5.6	5.5	9.3	0.7	0.9
December	166	151	241	253	43.3	15.8	8.0	9.3	4.8	5.3	1.5	1.9
2012 - Max.	1056	1440	1581	1594	311.5	117.5	80.3	71.9	181.7	335.6	91.0	258.8
2012 - Avg.	657	864	714	687	12.1	13.5	7.6	7.2	28.6	42.7	6.8	8.4
2012 - Med.	682	826	721	660	9.8	11.8	6.3	6.3	18.2	21.2	4.1	2.9
2012 - Min.	187	331	254	254	1.4	1.7	1.0	1.3	1.7	1.8	0.4	0.3
2012 - S.D.	187	222	230	234	14.7	7.1	5.1	4.5	27.2	50.6	8.8	20.3



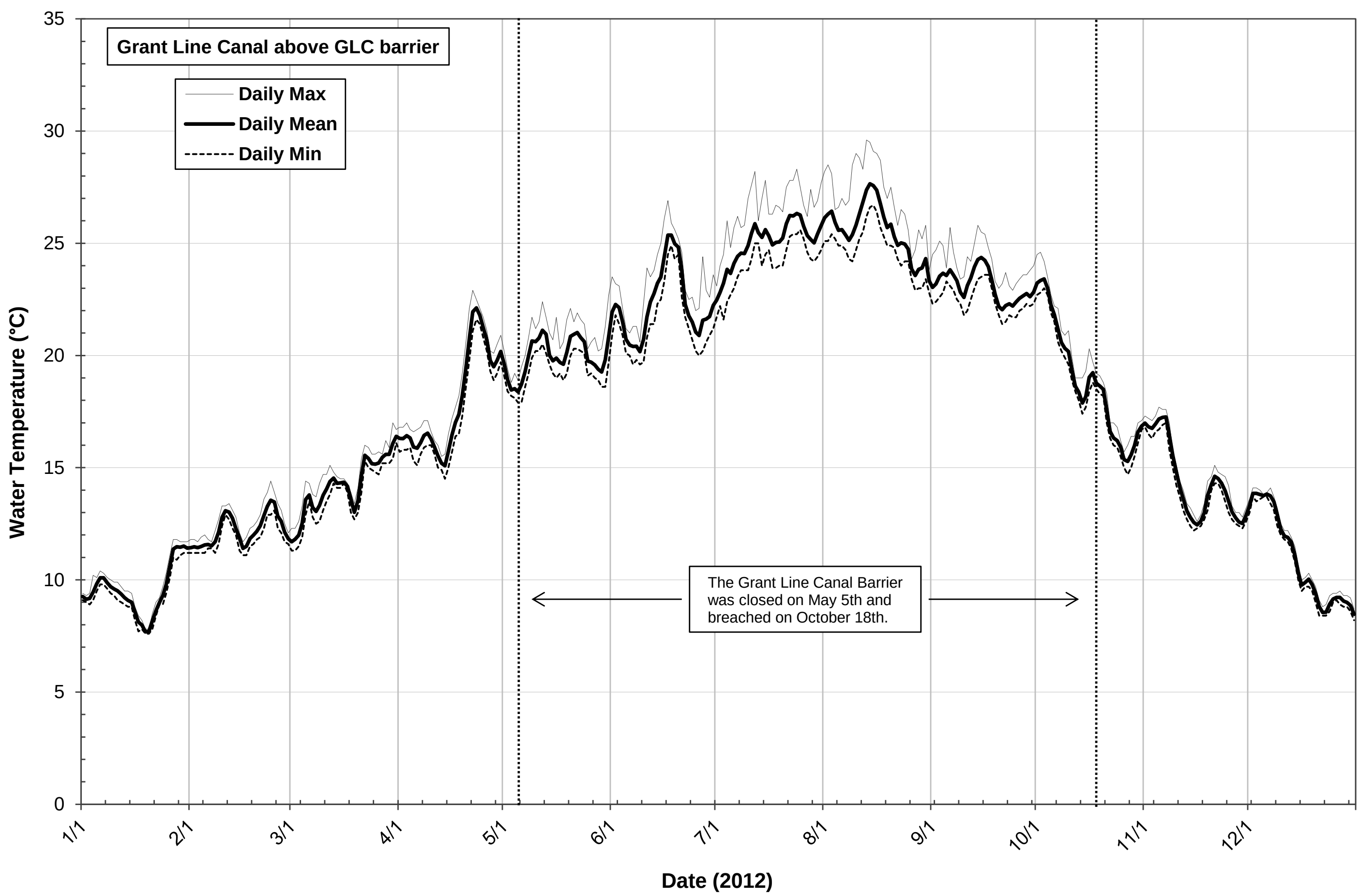
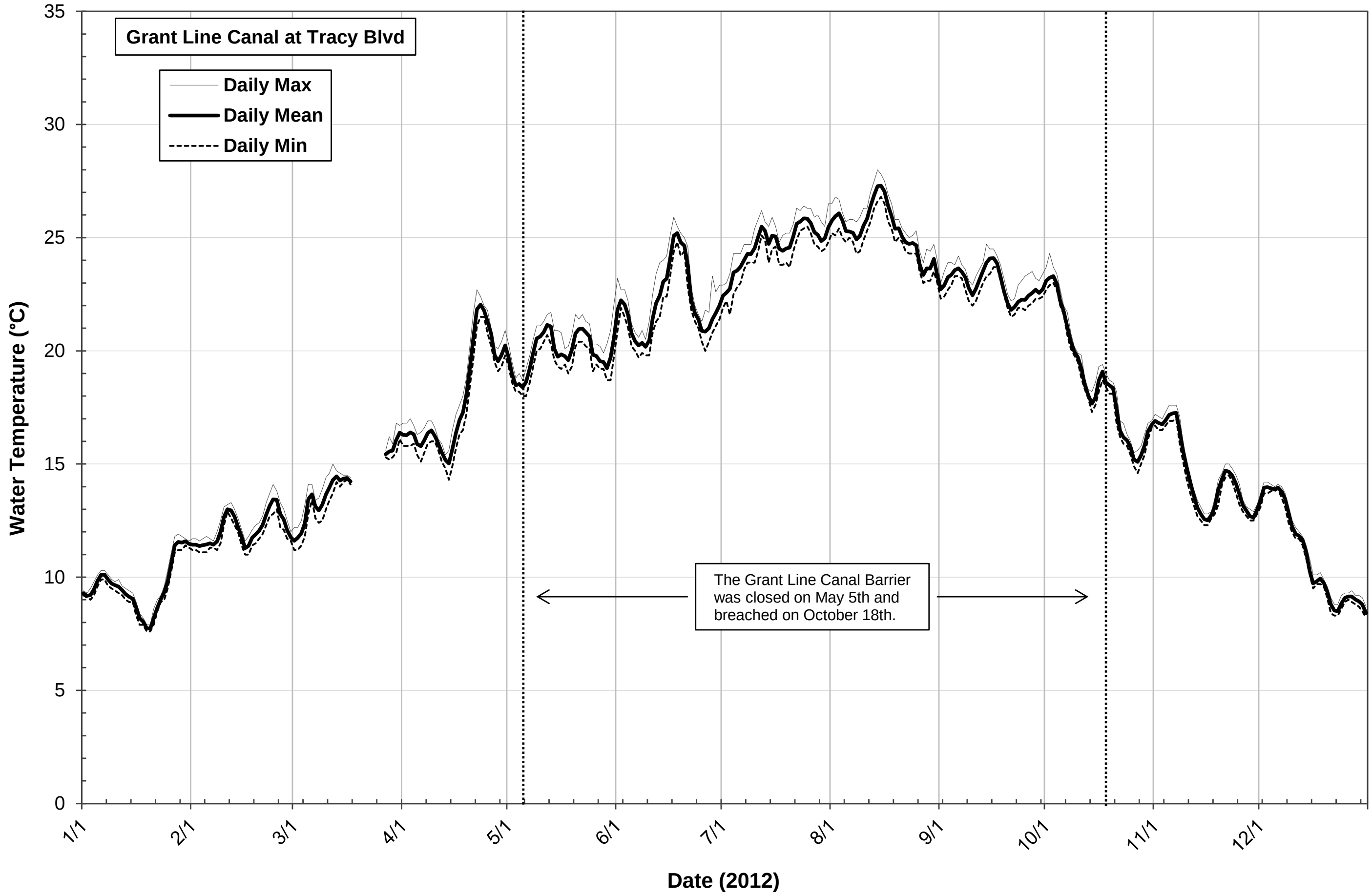


Figure 5-2: Daily Temperature time-series graphs for the Grant Line and Victoria Canal stations



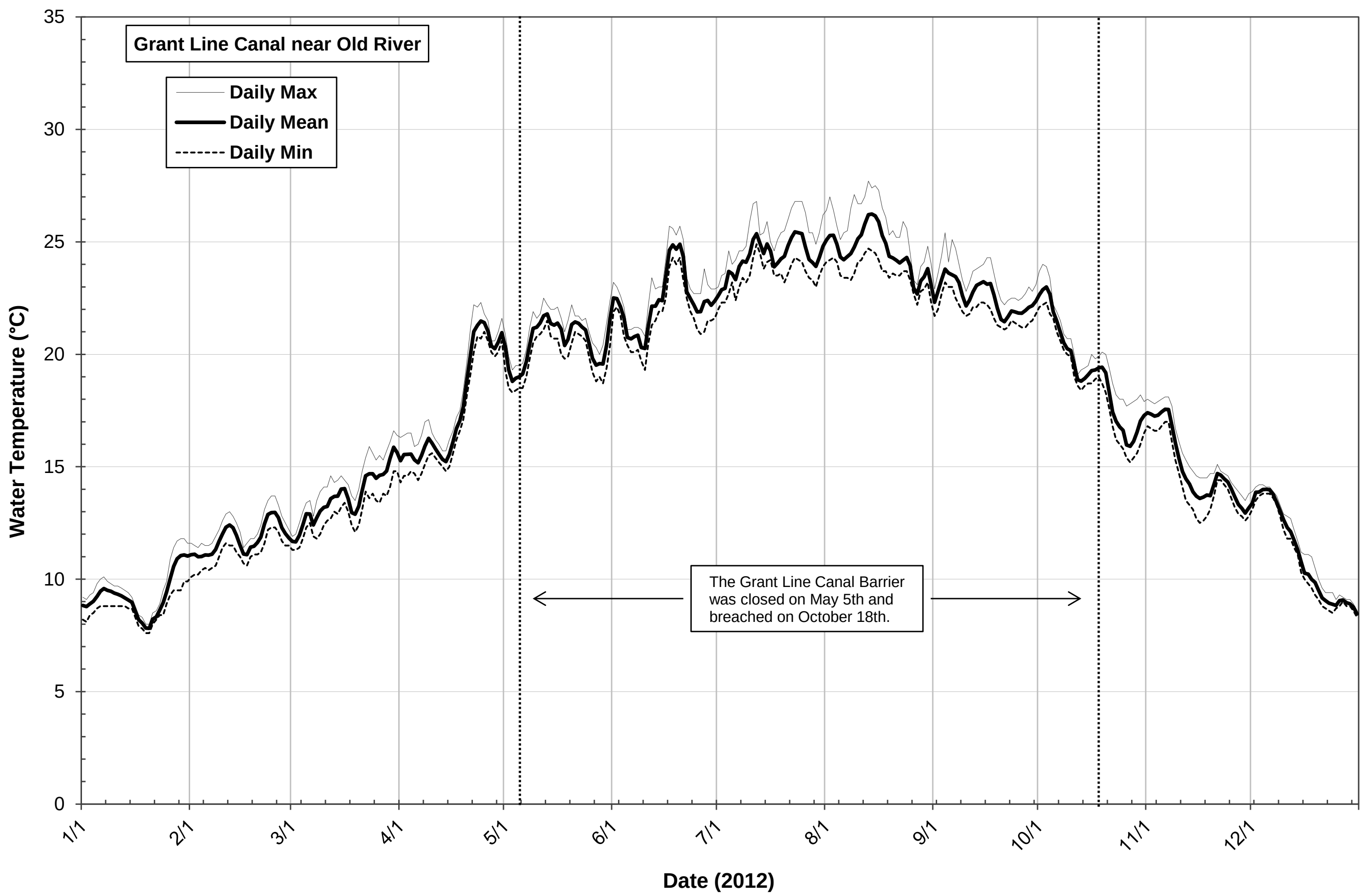


Figure 5-2: Daily Temperature time-series graphs for the Grant Line and Victoria Canal stations

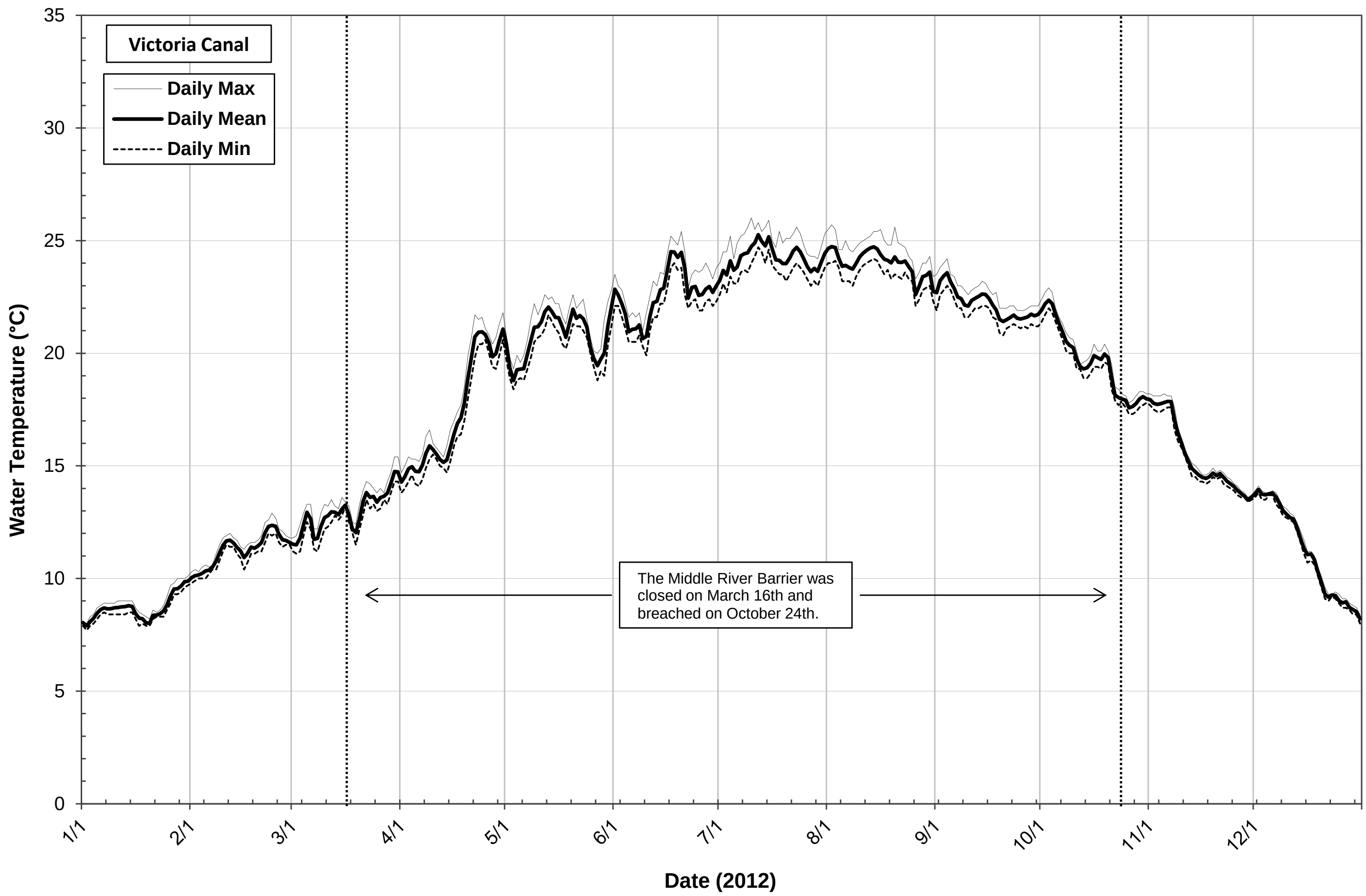
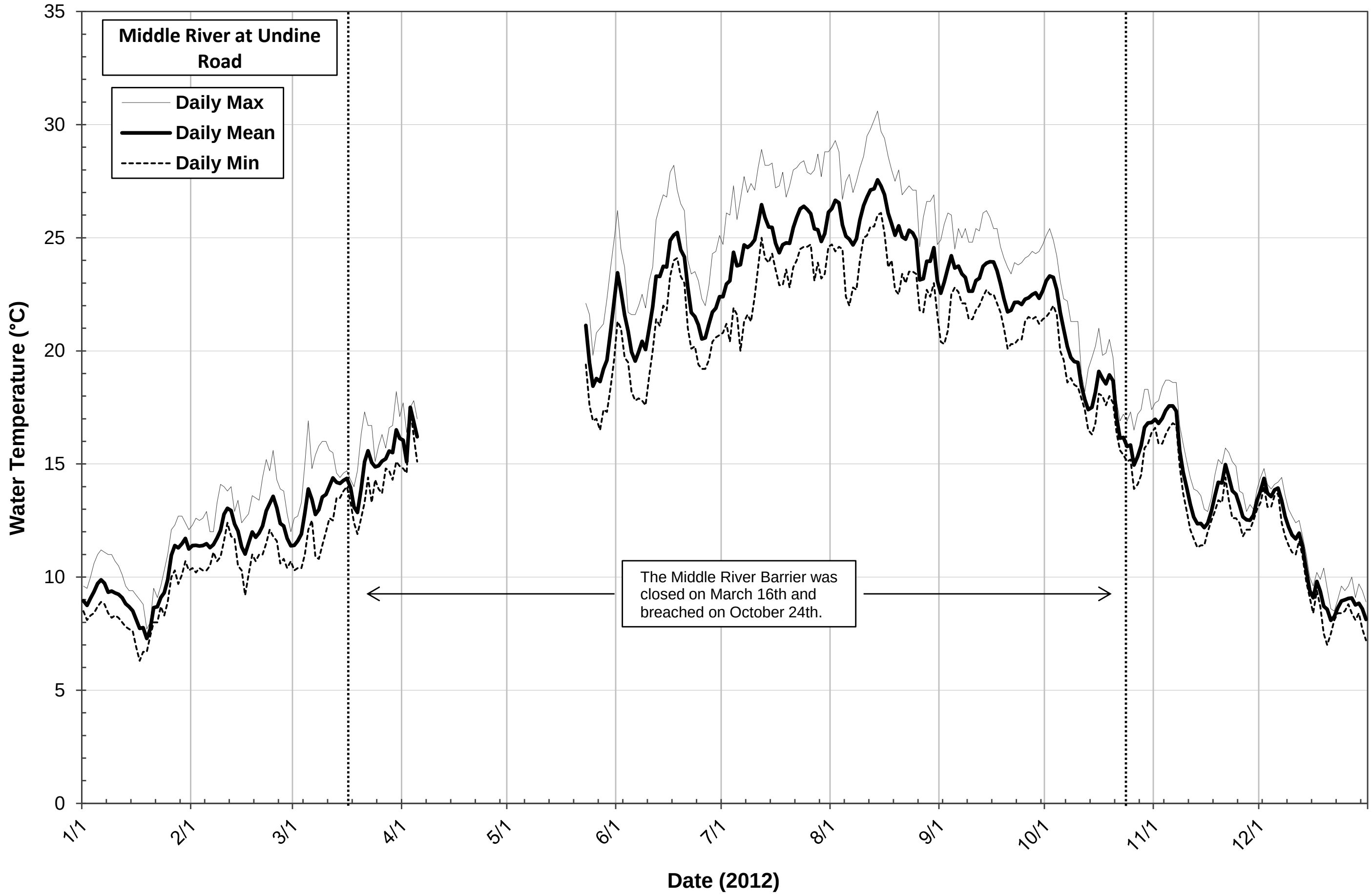


Figure 5-2: Daily Temperature time-series graphs for the Grant Line and Victoria Canal stations



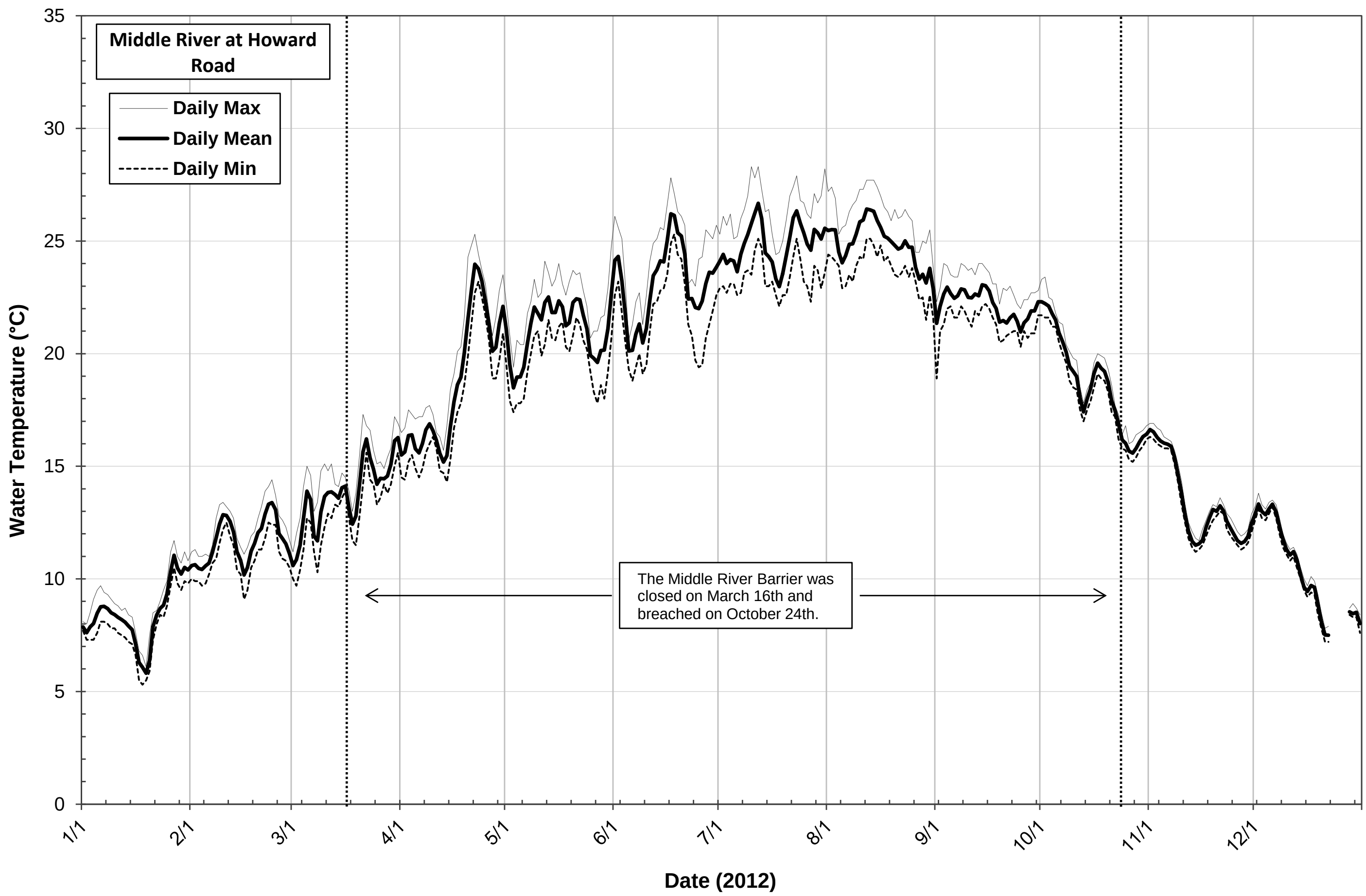
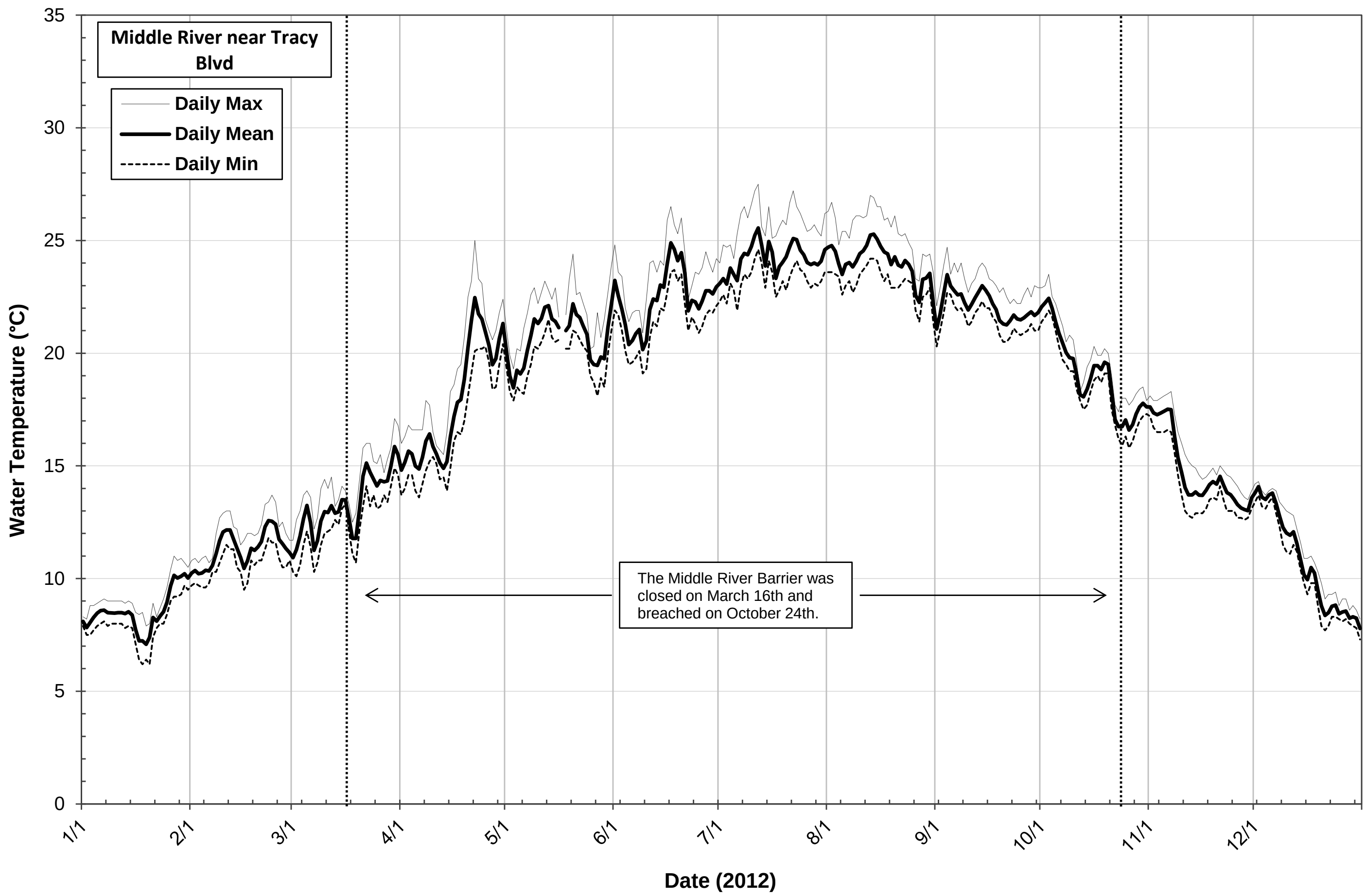


Figure 5-3: Daily Temperature time-series graphs for the Middle River stations



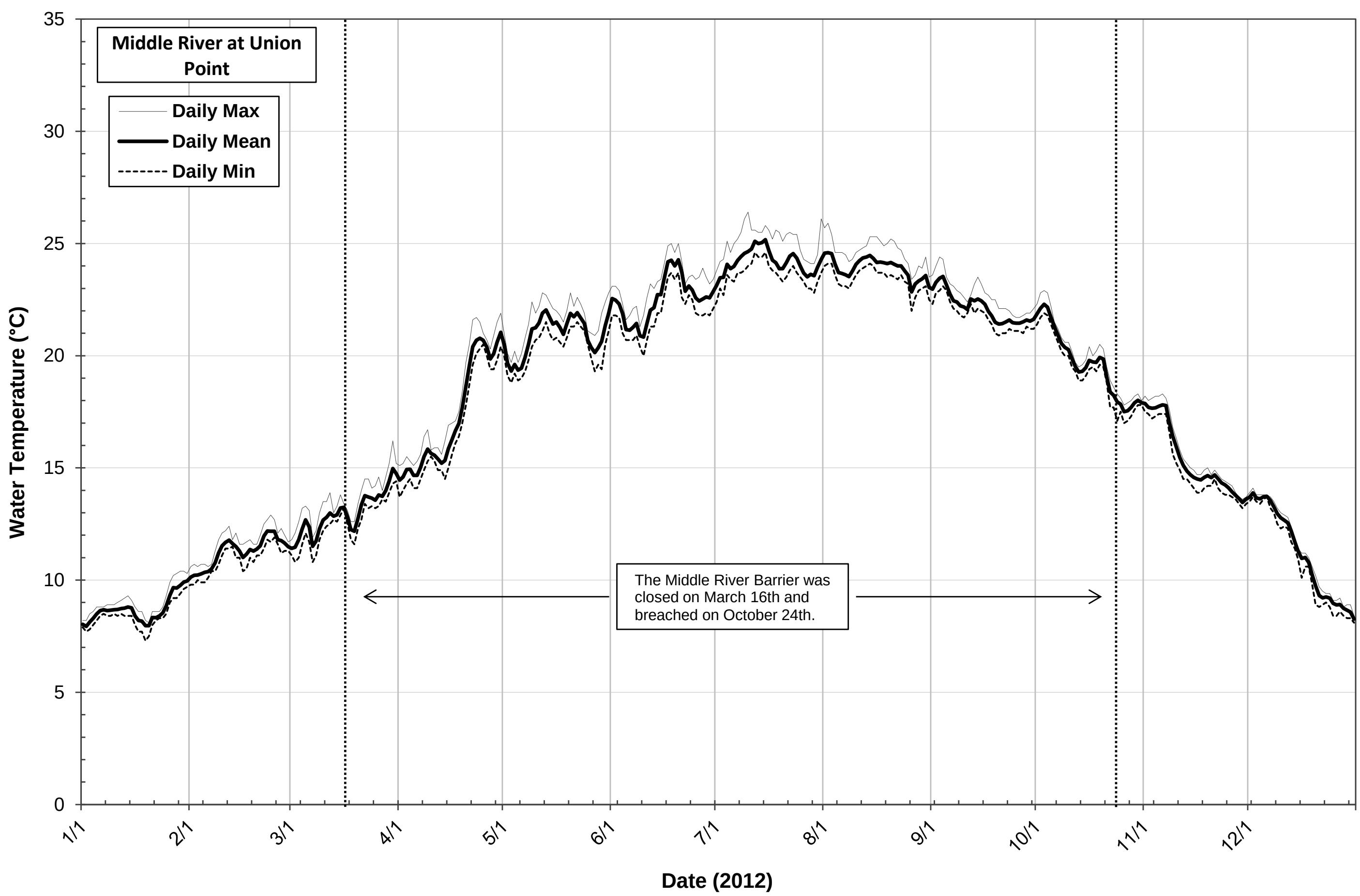
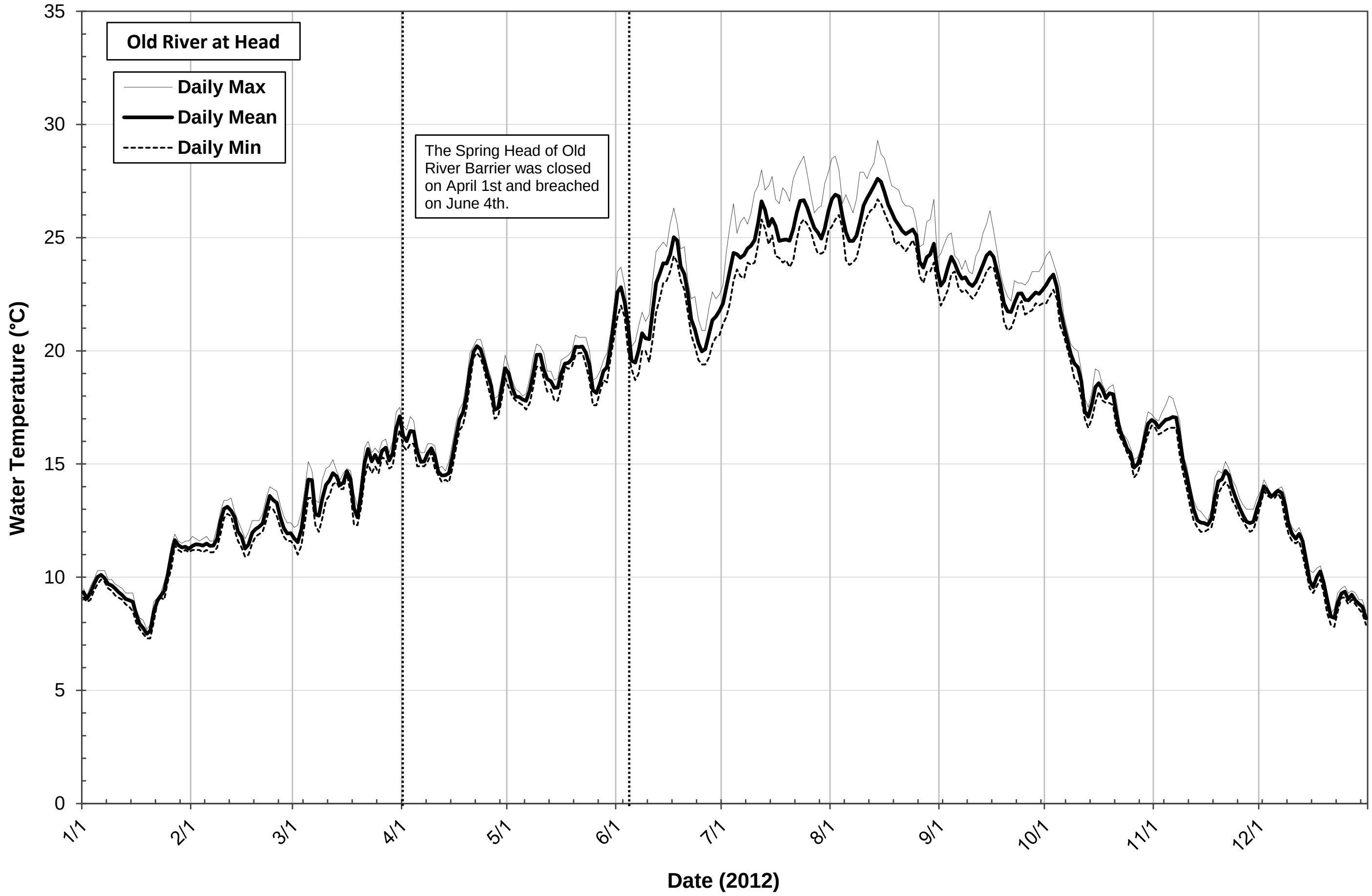


Figure 5-3: Daily Temperature time-series graphs for the Middle River stations



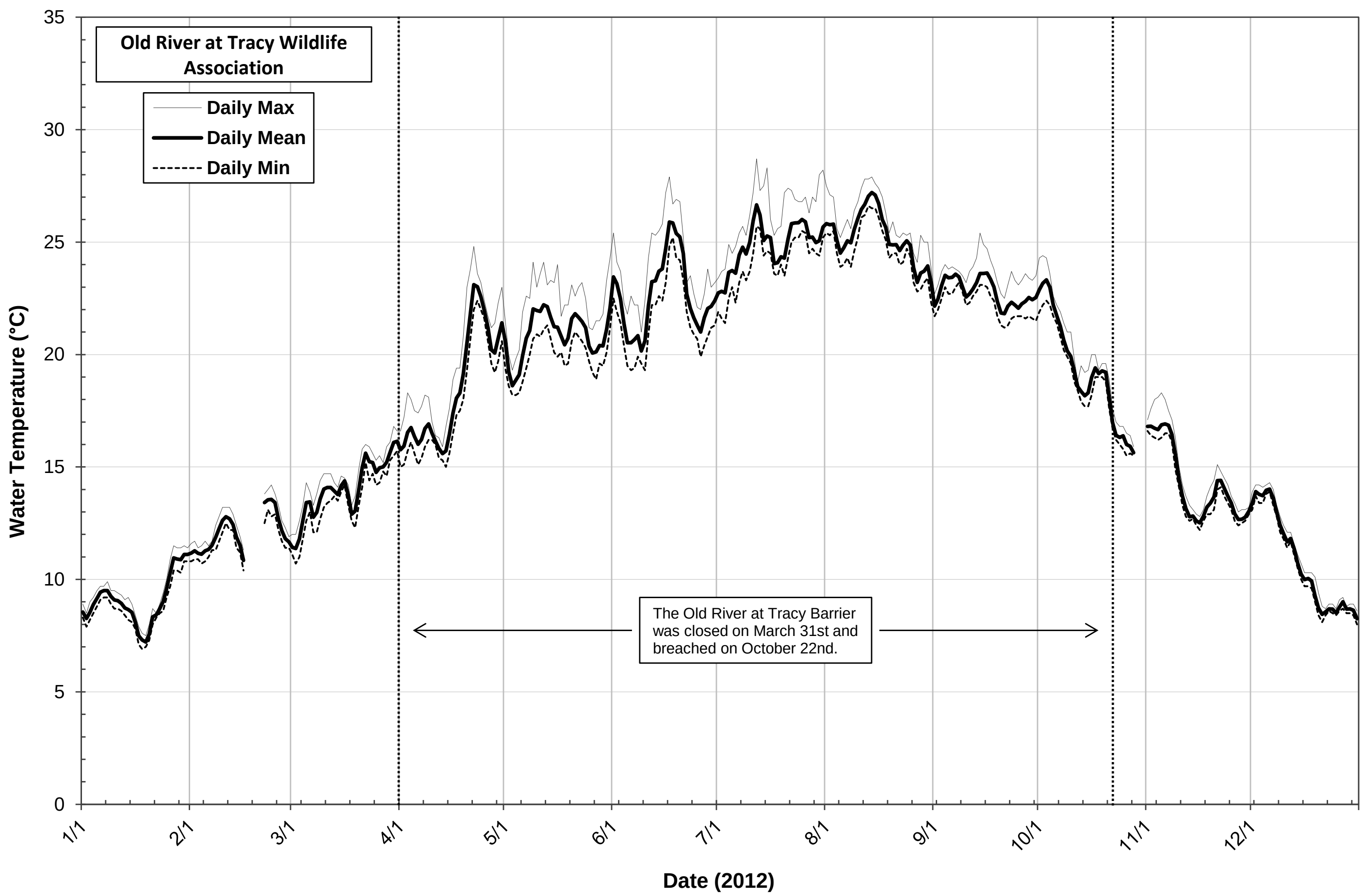
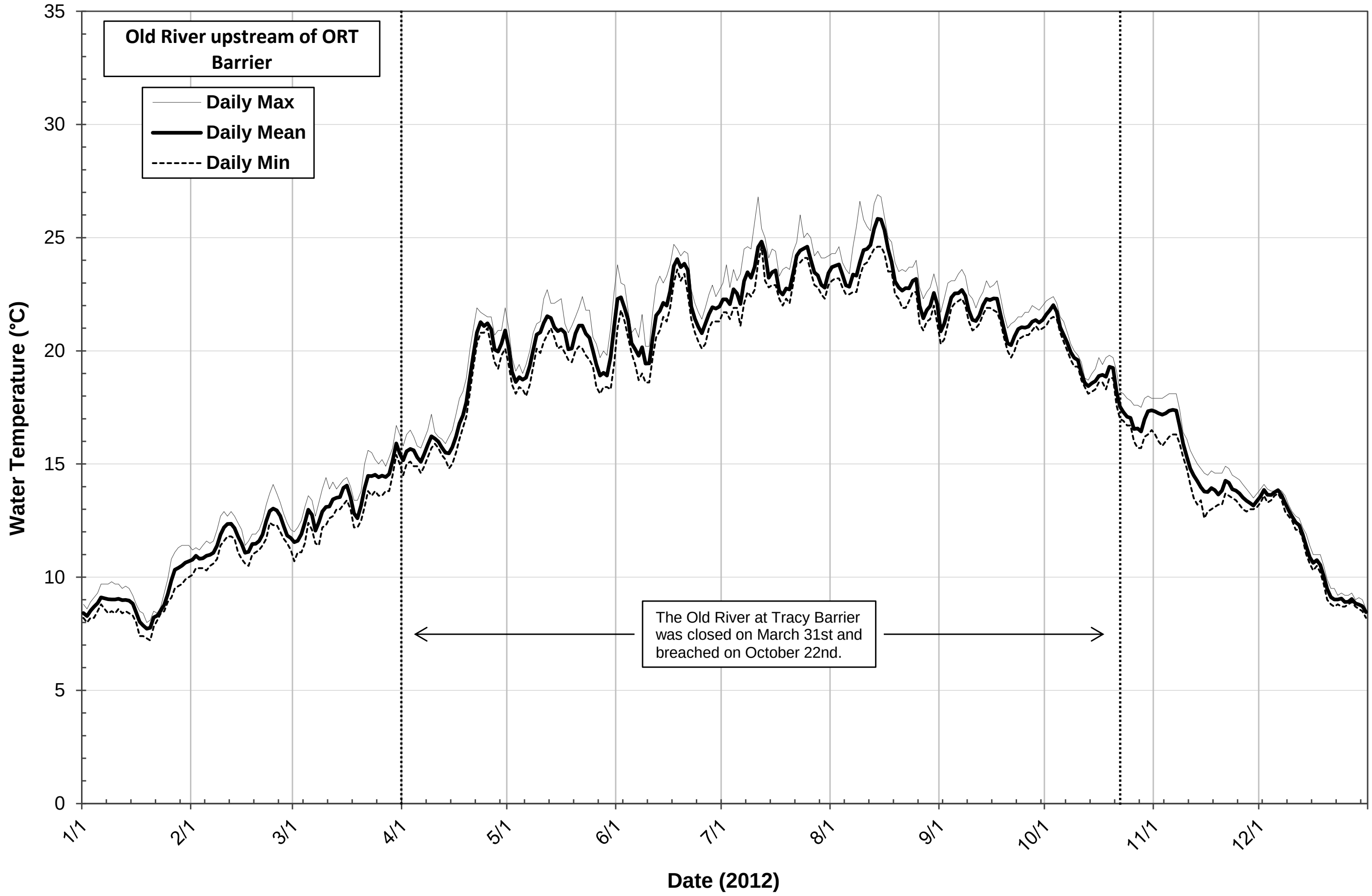


Figure 5-4: Daily Temperature time-series graphs for the Old River stations



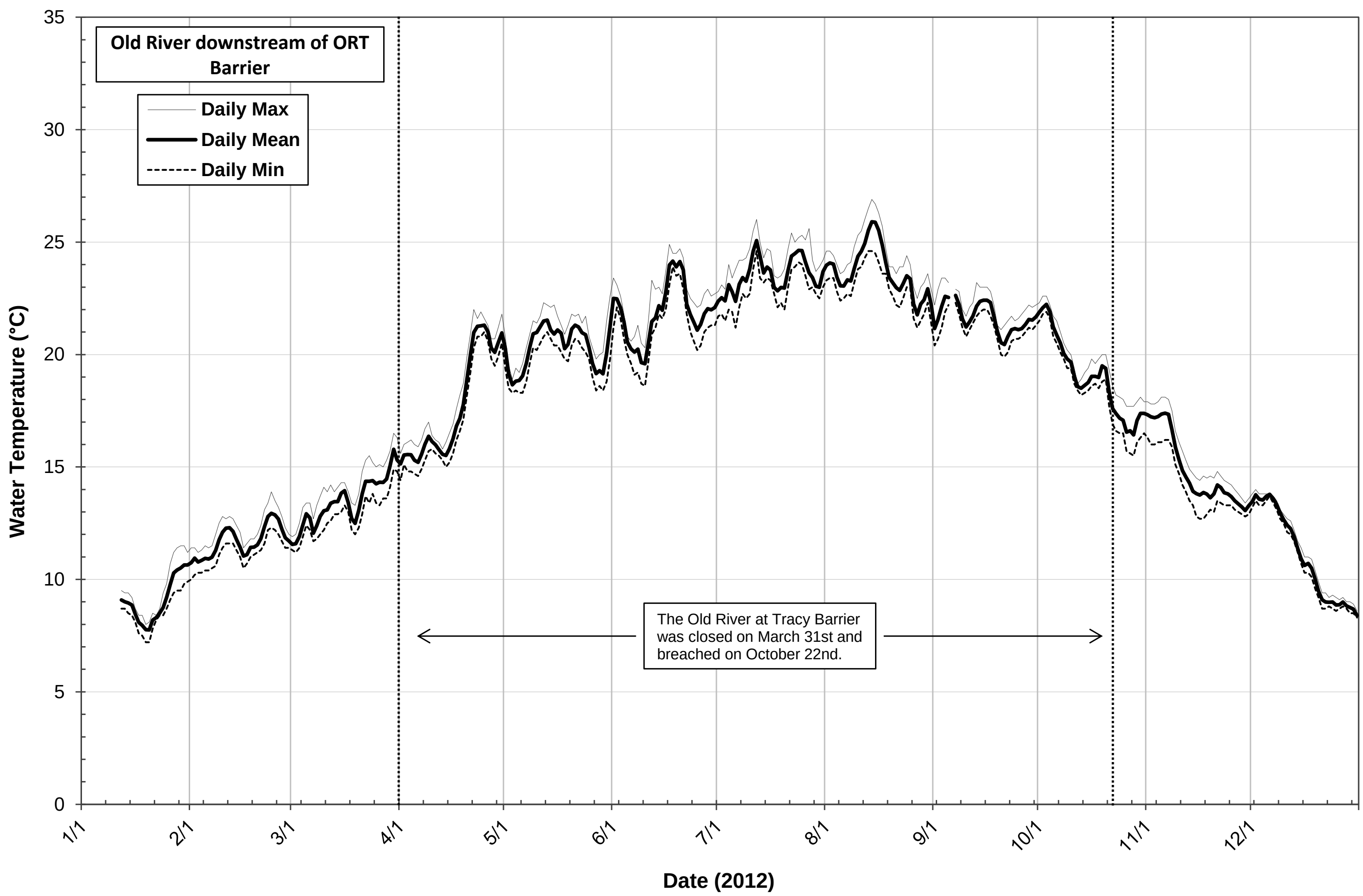


Figure 5-4: Daily Temperature time-series graphs for the Old River stations

Dissolved Oxygen

One of the most important measures of water quality is the amount of dissolved oxygen (Masters, 1997). Sources of dissolved oxygen in surface waters are primarily atmospheric reaeration and photosynthetic activity of aquatic plants (Lewis, 2005). Dissolved oxygen saturation is inversely related to water temperature (i.e. as water temperature increases, dissolved oxygen saturation decreases). Super saturated dissolved oxygen conditions can occur as a result of high rates of photosynthetic production of oxygen by phytoplankton and/or aquatic plants. The depletion of dissolved oxygen can occur by inorganic oxidation reactions or by biological or chemical processes that consume dissolved, suspended, or precipitated organic matter (Hem, 1989).

During the 2012 monitoring period, a maximum dissolved oxygen concentration of 23.84 mg/L was recorded on April 8th at Old River at Tracy Wildlife Association, and a minimum of 0.23 mg/L was recorded on August 25th at Middle River at Howard Road (Tables 5-3 to 5-6). Figures 5-5, 5-6, and 5-7 illustrate the daily maximums, minimums, and averages for the Grant Line and Victoria Canal, Middle River, and Old River stations, respectively.

At most of the stations during spring, there were two periods of time with obvious increases in dissolved oxygen concentrations: one in mid-March and the other in early April. Monthly average concentrations during the spring season (March – May) ranged from 6.81 mg/L in May at Middle River at Howard Road to 11.25 mg/L in March at Old River at Tracy Wildlife Association. Increases in dissolved oxygen are common during spring as a result of an increase in photosynthetic activity in the water. Chlorophyll *a* concentrations peaked at most stations during mid-March, which explains the increase in dissolved oxygen (Figures 5-29, 5-30, and 5-31). In May there was a decline in dissolved oxygen concentrations at most stations. Water temperature increased precipitously during spring going from 15°C in April to about 20°C during May, which explains the decline in dissolved oxygen concentrations during May.

Dissolved oxygen concentrations are typically lowest during summer and early fall months because of high water temperatures. This phenomenon was observed at most sites during 2012. Monthly average summer dissolved oxygen concentrations (June-August) ranged from 11.76 mg/L at Old River at Head to 2.35 mg/L at Middle River at Howard Road (Tables 5-3, 5-4, 5-5, and 5-6). Dissolved oxygen concentrations fell below 5 mg/L at most of the South Delta stations during summer. Middle River at Howard Road had the longest duration of daily average dissolved oxygen concentrations below 5 mg/L, from July through October (Figure 5-6).

At the beginning of November, dissolved oxygen concentrations at all of the stations started to increase, which was most likely due to decreasing water temperatures. During November and December 2012, monthly average concentrations ranged from 7.08 mg/L at Middle River at Howard Road to 11.15 mg/L at Middle River at Undine Road (Tables 5-3, 5-4, 5-5, and 5-6). Monthly average water temperature readings during November and December 2012 ranged from 15.4°C (59.7°F) at Victoria Canal and Middle River at Union Point to 10.6°C (51.1°F) at Middle River at Undine Road and Middle River at Howard Road. Dissolved oxygen concentrations increased during November and December due to lower water temperatures.

Water Quality Standard Exceedences:

As discussed in the Methods and Results section, the established dissolved oxygen criteria is 5 mg/L; therefore, staff considered any dissolved oxygen sample of reliable data quality less than 5.0 mg/L as exceeding the standard. Figures 5-8, 5-9, and 5-10 illustrate the number of dissolved oxygen readings with concentrations less than 5.0 mg/L for each season and the overall total for the 2012 monitoring period for the Grant Line and Victoria Canal, Middle River, and Old River stations, respectively. In addition, the figures show the percent of sonde samples exceeding the dissolved oxygen standard relative to the total number of samples collected. Figures 5-11, 5-12, and 5-13 provide the exceedence information in a map format allowing for the observation of geographical relationships.

The station with the most exceedences during 2012 was Middle River at Howard Road with a total of 10,890 (31% of the total number of samples). Most of the standard exceedences at the Howard Road station occurred during summer (6,438; 73% of all samples collected in the summer) and the fall (3,901; 45% of all samples collected in the fall).

Two stations had no dissolved oxygen readings with values less than 5 mg/L during 2012: Victoria Canal and Middle River at Union Point. For the stations that had dissolved oxygen exceedences during 2012, most of the exceedences occurred during the summer and fall seasons.

For the stations located along Old River, the stations closest to the ORT barrier had a higher number of exceedences during 2012 than the stations further upstream. (Figures 5-10 and 5-13). The Old River upstream of the ORT barrier station had 8,207 total exceedences (23% of all samples) and the station downstream of the barrier had 5,791 total exceedences (about 17% of all samples). The number of total exceedences (4,062; 12% of all samples) at the Old River at Tracy Wildlife Association station was about 5% less in comparison to the downstream of the ORT barrier station.

For the Grant Line Canal stations, Grant Line Canal at Tracy Blvd had the most total exceedences, with 3,418 (about 10% of all samples). Grant Line Canal above Barrier had 2,280 (about 6% of all samples) total exceedences and Grant Line Canal near Old River had 1,586 (about 5% of all samples) total exceedences. The difference in dissolved oxygen exceedences between GLC above Barrier and GLC near Old River was about 1%, showing that dissolved oxygen conditions at these two locations were fairly analogous. (Figures 5-8 and 5-11)

Each of the stations located upstream of the Middle River barrier had more total exceedences compared to the downstream station, Middle River at Union Point, which didn't have any exceedences. (Figures 5-9 and 5-12).

Station Comparisons by Season:

Grant Line Canal

Grant Line Canal near Old River station had significantly lower dissolved oxygen concentrations than the three other stations along Grant Line Canal during Fall ($p<0.00000$; Table 5-9) Doughty Cut had significantly higher dissolved oxygen concentrations during summer and fall (summer: $p<0.00001$, fall: $p<0.00000$; Tables 5-8 and 5-9).

Table 5-7: Seasonal Medians and p-values for the Dunn's multiple comparison procedure for the Grant Line Canal stations - **Spring**

Station	Seasonal Median DO Conc (mg/L)	Pair-wise Comparison p-value [a]			
		GLC near OR	GLC at Tracy Blvd	GLC above barrier	Doughty Cut abv GLC
GLC near OR	8.30	--	NS	0.03602	0.00162
GLC at Tracy Blvd	8.58	NS	--	NS	NS
GLC above barrier	8.81	0.03602	NS	--	NS
Doughty Cut abv GLC	9.41	0.00162	NS	NS	--

[a] "NS" stands for "no significant difference between the two stations" in all of these tables.

Table 5-8: Seasonal Medians and p-values for the Dunn's multiple comparison procedure for the Grant Line Canal stations - **Summer**

Station	Seasonal Median DO Conc (mg/L)	Pair-wise Comparison p-value			
		GLC at Tracy Blvd	GLC near OR	GLC above barrier	Doughty Cut abv GLC
GLC at Tracy Blvd	6.01	--	NS	NS	0.00000
GLC near OR	6.53	NS	--	0.00530	0.00000
GLC above barrier	7.19	NS	0.00530	--	0.00001
Doughty Cut abv GLC	8.33	0.00000	0.00000	0.00001	--

Table 5-9: Seasonal Medians and p-values for the Dunn's multiple comparison procedure for the Grant Line Canal stations - **Fall**

Station	Seasonal Median DO Conc (mg/L)	Pair-wise Comparison p-value			
		GLC near OR	GLC at Tracy Blvd	GLC above barrier	Doughty Cut abv GLC
GLC near OR	7.92	--	0.00000	0.00000	0.00000
GLC at Tracy Blvd	8.77	0.00000	--	NS	0.00000
GLC above barrier	8.92	0.00000	NS	--	0.00000
Doughty Cut abv GLC	9.48	0.00000	0.00000	0.00000	--

Middle River

Middle River at Undine Road had significantly higher dissolved oxygen concentrations compared to the other three sites for each season ($p<0.01062$; Tables 5-10, 5-11, and 5-12). Middle River at Howard Road had significantly lower dissolved oxygen concentrations compared to the other three sites during summer and fall (summer: $p<0.00000$, fall: $p<0.00356$; Tables 5-11 and 5-12).

Table 5-10: Seasonal Medians and p-values for the Dunn's multiple comparison procedure for the Middle River stations - **Spring**

Station	Seasonal Median DO Conc (mg/L)	Pair-wise Comparison p-value [a]			
		Middle River at Howard Rd	Middle River nr Tracy Blvd	Middle River at Union Point	Middle River at Undine Rd
Middle River at Howard Rd	8.17	--	NS	NS	0.00000
Middle River near Tracy Blvd	8.40	NS	--	NS	0.00000
Middle River at Union Point	9.02	NS	NS	--	0.00000
Middle River at Undine Rd	10.07	0.00000	0.00000	0.00000	--

[a] "NS" stands for "no significant difference between the two stations" in all of these tables.

Table 5-11: Seasonal Medians and p-values for the Dunn's multiple comparison procedure for the Middle River stations - **Summer**

Station	Seasonal Median DO Conc (mg/L)	Pair-wise Comparison p-value			
		Middle River at Howard Rd	Middle River nr Tracy Blvd	Middle River at Union Point	Middle River at Undine Rd
Middle River at Howard Rd	3.41	--	0.00000	0.00000	0.00000
Middle River near Tracy Blvd	5.99	0.00000	--	0.00000	0.00000
Middle River at Union Point	7.78	0.00000	0.00000	--	0.01062
Middle River at Undine Rd	9.63	0.00000	0.00000	0.01062	--

Table 5-12: Seasonal Medians and p-values for the Dunn's multiple comparison procedure for the Middle River stations - **Fall**

Station	Seasonal Median DO Conc (mg/L)	Pair-wise Comparison p-value			
		Middle River at Howard Rd	Middle River nr Tracy Blvd	Middle River at Union Point	Middle River at Undine Rd
Middle River at Howard Rd	5.38	--	0.00356	0.00000	0.00000
Middle River near Tracy Blvd	5.94	0.00356	--	0.00000	0.00000
Middle River at Union Point	8.18	0.00000	0.00000	--	0.00000
Middle River at Undine Rd	9.92	0.00000	0.00000	0.00000	--

Old River

Old River at Head had significantly higher dissolved oxygen concentrations than the three other Old River stations during every season analyzed (spring: $p<0.00000$, summer: $p<0.00000$, fall: $p<0.00000$; Tables 5-13 to 5-15). Old River upstream of the barrier had significantly lower dissolved oxygen concentrations compared to the other 3 stations for fall ($p<0.01794$). The dissolved oxygen concentrations at the two stations adjacent to the ORT barrier were not significantly different during the spring, and summer ($p>0.05$, Tables 5-13 and 5-14).

Table 5-13: Seasonal Medians and p-values for the Dunn's multiple comparison procedure for the Old River stations - **Spring**

Station	Seasonal Median DO Conc (mg/L)	Pair-wise Comparison p-value [a]			
		Old River u/s ORT barrier	Old River d/s ORT barrier	Old River at TWA	Old River at Head
Old River u/s ORT barrier	7.96	--	NS	0.00036	0.00000
Old River d/s ORT barrier	8.31	NS	--	NS	0.00000
Old River at TWA	9.07	0.00036	NS	--	0.00000
Old River at Head	10.06	0.00000	0.00000	0.00000	--

[a] "NS" stands for "no significant difference between the two stations" in all of these tables.

Table 5-14: Seasonal Medians and p-values for the Dunn's multiple comparison procedure for the Old River stations - **Summer**

Station	Seasonal Median DO Conc (mg/L)	Pair-wise Comparison p-value			
		Old River u/s ORT barrier	Old River d/s ORT barrier	Old River at TWA	Old River at Head
Old River u/s ORT barrier	5.68	--	NS	0.00211	0.00000
Old River d/s ORT barrier	6.12	NS	--	NS	0.00000
Old River at TWA	6.38	0.00211	NS	--	0.00000
Old River at Head	11.54	0.00000	0.00000	0.00000	--

Table 5-15: Seasonal Medians and p-values for the Dunn's multiple comparison procedure for the Old River stations - **Fall**

Station	Seasonal Median DO Conc (mg/L)	Pair-wise Comparison p-value			
		Old River u/s ORT barrier	Old River d/s ORT barrier	Old River at TWA	Old River at Head
Old River u/s ORT barrier	4.47	--	0.01794	0.00000	0.00000
Old River d/s ORT barrier	4.88	0.01794	--	0.01094	0.00000
Old River at TWA	7.03	0.00000	0.01094	--	0.00000
Old River at Head	10.08	0.00000	0.00000	0.00000	--

Upstream/Downstream Station Comparisons:

Grant Line Canal Barrier

The upstream station, Grant Line Canal above the GLC barrier, had significantly higher dissolved oxygen concentrations than the downstream station, Grant Line Canal at Tracy Blvd, for seven months during 2012 (Table 5-16). There was no significant difference in dissolved oxygen concentrations ($p>0.5$) between the two stations during March, April, May, June, and December 2012.

Table 5-16: Results for the Upstream-Downstream Analysis for the Grant Line Canal barrier

	Monthly Median DO Conc (mg/L) [a]		Mann-Whitney Test Results [b]		
Month	**Upstream Station - GLC above the barrier**	**Downstream Station - GLC at Tracy Blvd**	**p-value**	**Difference between Monthly Medians (mg/L)**	**Station with significantly higher DO values [c]**
January	11.43	11.12	0.017	0.32	GLAB
February	10.15	9.91	0.0001	0.24	GLAB
March	10.78	10.48	NS	NS	NS
April	9.41	8.90	NS	NS	NS
May	7.71	7.56	NS	NS	NS
June	9.60	8.89	NS	NS	NS
July	8.48	5.16	<0.0001	3.32	GLAB
August	7.30	4.55	<0.0001	2.75	GLAB
September	10.00	8.02	<0.0001	1.98	GLAB
October	9.08	8.66	<0.0001	0.41	GLAB
November	9.60	9.45	0.032	0.15	GLAB
December	9.61	9.36	NS	NS	NS

(a) The monthly medians are actually the medians of the daily medians for the month. For example, in this analysis the monthly median for January is the median of all of the daily medians for the month of January.

(b) "NS" stands for "no significant difference between the two stations".

(c) "GLTR" represents the Grant Line Canal at Tracy Blvd station. "GLAB" represents the Grant Line Canal above the GLC barrier station.

Middle River Barrier

The upstream station, Middle River near Tracy Blvd, had significantly higher dissolved oxygen concentrations than the downstream station, Middle River at Union Point, during the cooler months of 2012 (January, and February; Table 5-17). During the warmer months (June –October 2012), Middle River at Union Point had significantly higher dissolved oxygen concentrations than Middle River near Tracy Blvd. The differences between the monthly medians of the two stations was largest during October, with a difference of 2.7mg/L.

Table 5-17: Results for the Upstream-Downstream Analysis for the Middle River barrier

	Monthly Median DO Conc (mg/L) [a]		Mann-Whitney Test Results [b]		
Month	Upstream Station - MR near Tracy Blvd	Downstream Station - MR at Union Point	p-value	Difference between Monthly Medians (mg/L)	Station with significantly higher DO values [c]
January	10.51	10.16	<0.0001	0.35	MRNT
February	9.79	9.48	<0.0001	0.31	MRNT
March	8.74	9.17	0.012	0.43	MRUP
April	8.97	9.14	NS	NS	NS
May	7.88	7.83	NS	NS	NS
June	6.73	7.77	<0.0001	1.04	MRUP
July	5.96	7.75	<0.0001	1.80	MRUP
August	5.51	7.85	<0.0001	2.34	MRUP
September	5.64	8.08	<0.0001	2.44	MRUP
October	5.41	8.11	<0.0001	2.70	MRUP
November	8.79	8.74	NS	NS	NS
December	8.86	8.75	NS	NS	NS

(a) The monthly medians are actually the medians of the daily medians for the month. For example, in this analysis the monthly median for January is the median of all of the daily medians for the month of January.

(b) "NS" stands for "no significant difference between the two stations".

(c) "MRNT" represents the Middle River near Tracy Blvd station. "MRUP" represents the Middle River at Union Point station.

Old River at Tracy Barrier

The downstream station, Old River downstream of the ORT barrier, had significantly higher dissolved oxygen concentrations than the upstream station, Old River upstream of the ORT barrier, during the months of February, March, May, July, October, and November 2012 (Table 5-18). There were no significant differences in dissolved oxygen concentrations between these two stations during the remaining months.

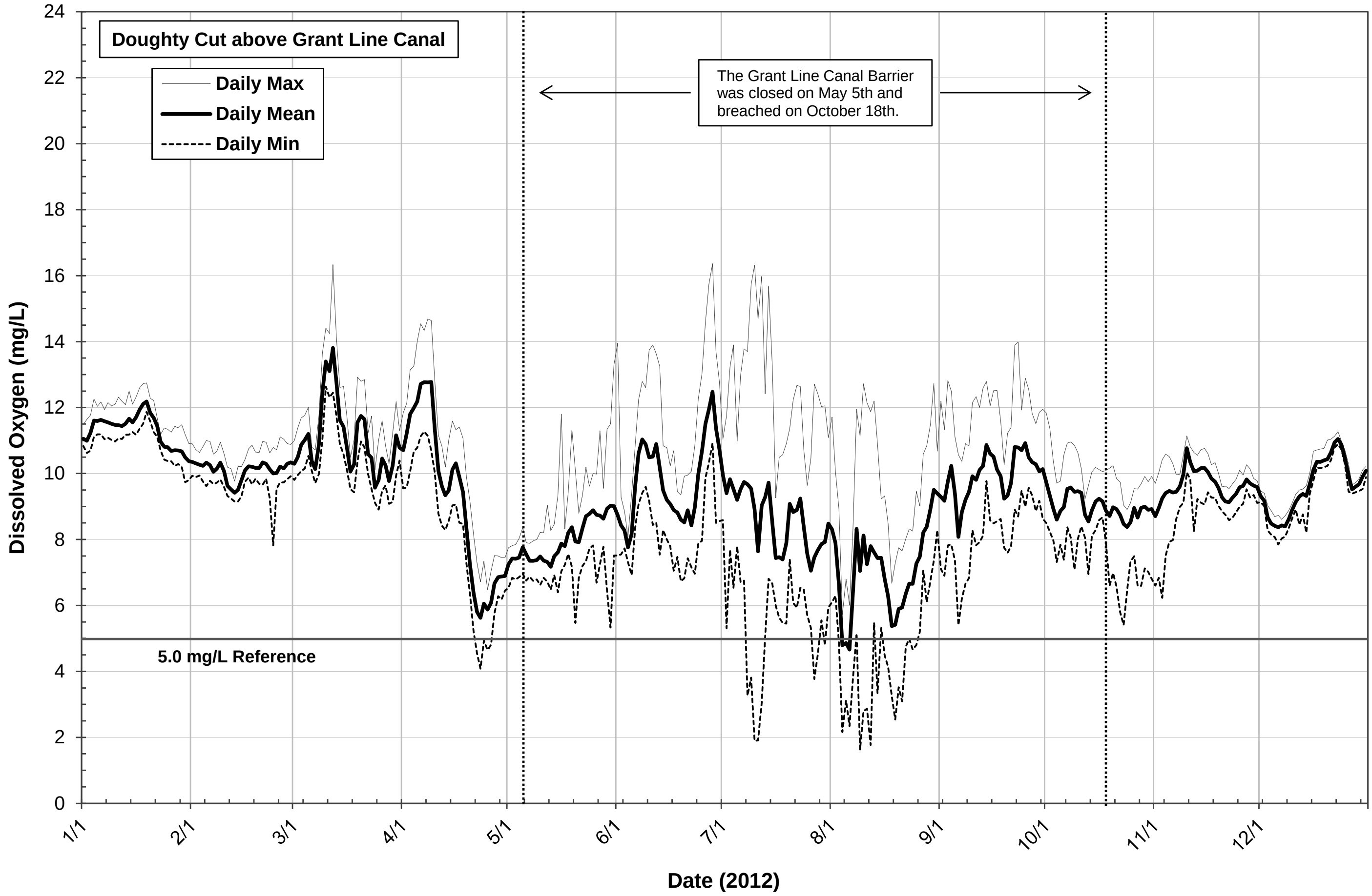
Table 5-18: Results for the Upstream-Downstream Analysis for the Old River at Tracy barrier

	Monthly Median DO Conc (mg/L) [a]		Mann-Whitney Test Results [b]		
Month	**Upstream Station - OR u/s ORT barrier**	**Downstream Station - OR d/s ORT barrier**	**p-value**	**Difference between Monthly Medians (mg/L)**	**Station with significantly higher DO values [c]**
January	10.42	10.37	NS	NS	NS
February	9.45	9.65	<0.0001	0.20	ORDB
March	8.95	9.66	0.0026	0.71	ORDB
April	7.98	8.37	NS	NS	NS
May	7.24	7.53	0.0047	0.29	ORDB
June	7.13	7.34	NS	NS	NS
July	4.99	5.64	0.0132	0.65	ORDB
August	4.07	4.49	NS	NS	NS
September	3.20	3.77	NS	NS	NS
October	3.86	4.58	0.0226	0.73	ORDB
November	7.02	8.02	<0.0001	1.00	ORDB
December	7.29	7.86	NS	NS	NS

(a) The monthly medians are actually the medians of the daily medians for the month. For example, in this analysis the monthly median for January is the median of all of the daily medians for the month of January.

(b) "NS" stands for "no significant difference between the two stations".

(c) "ORDB" represents the Old River downstream of the ORT barrier station.



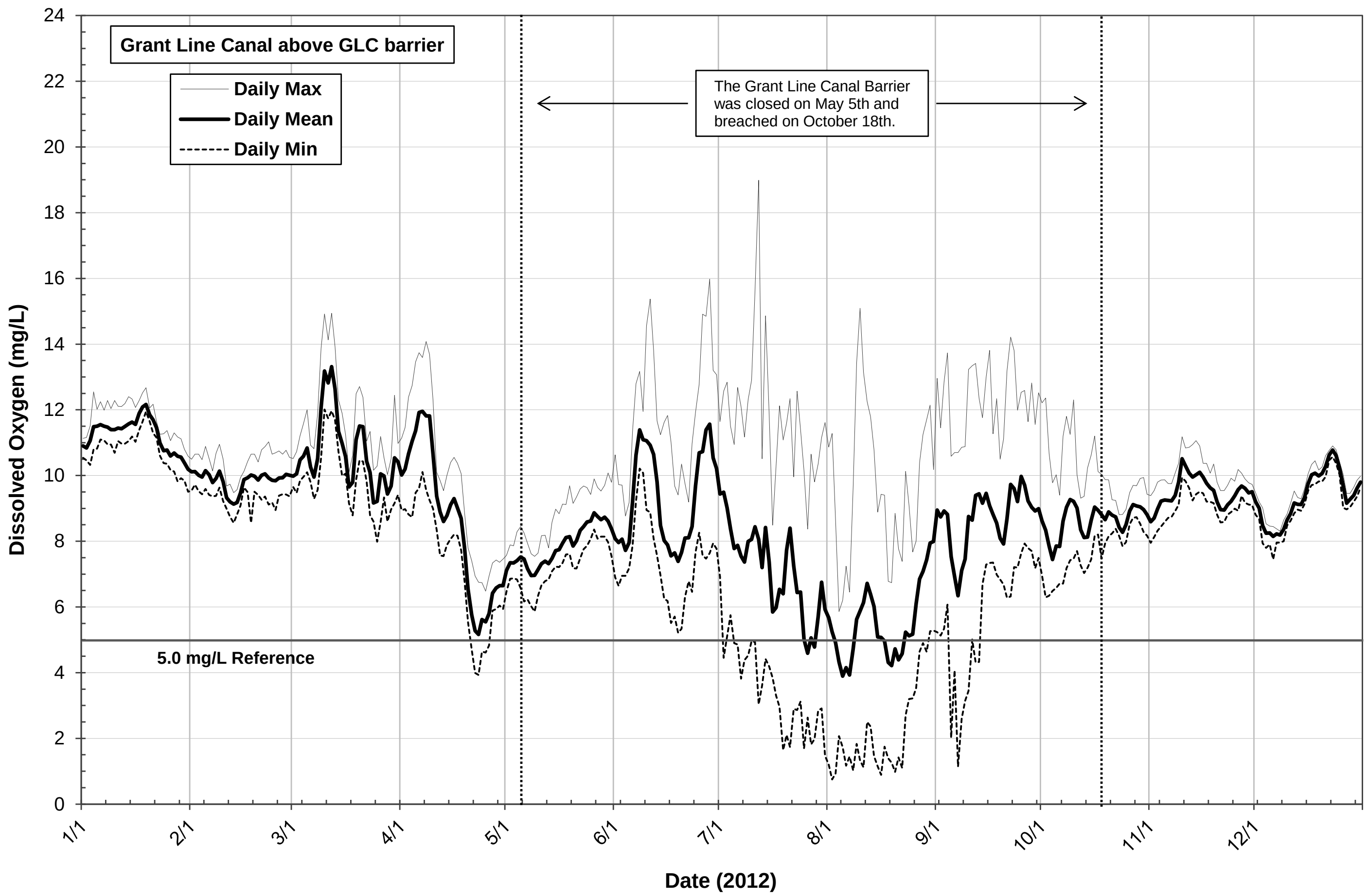
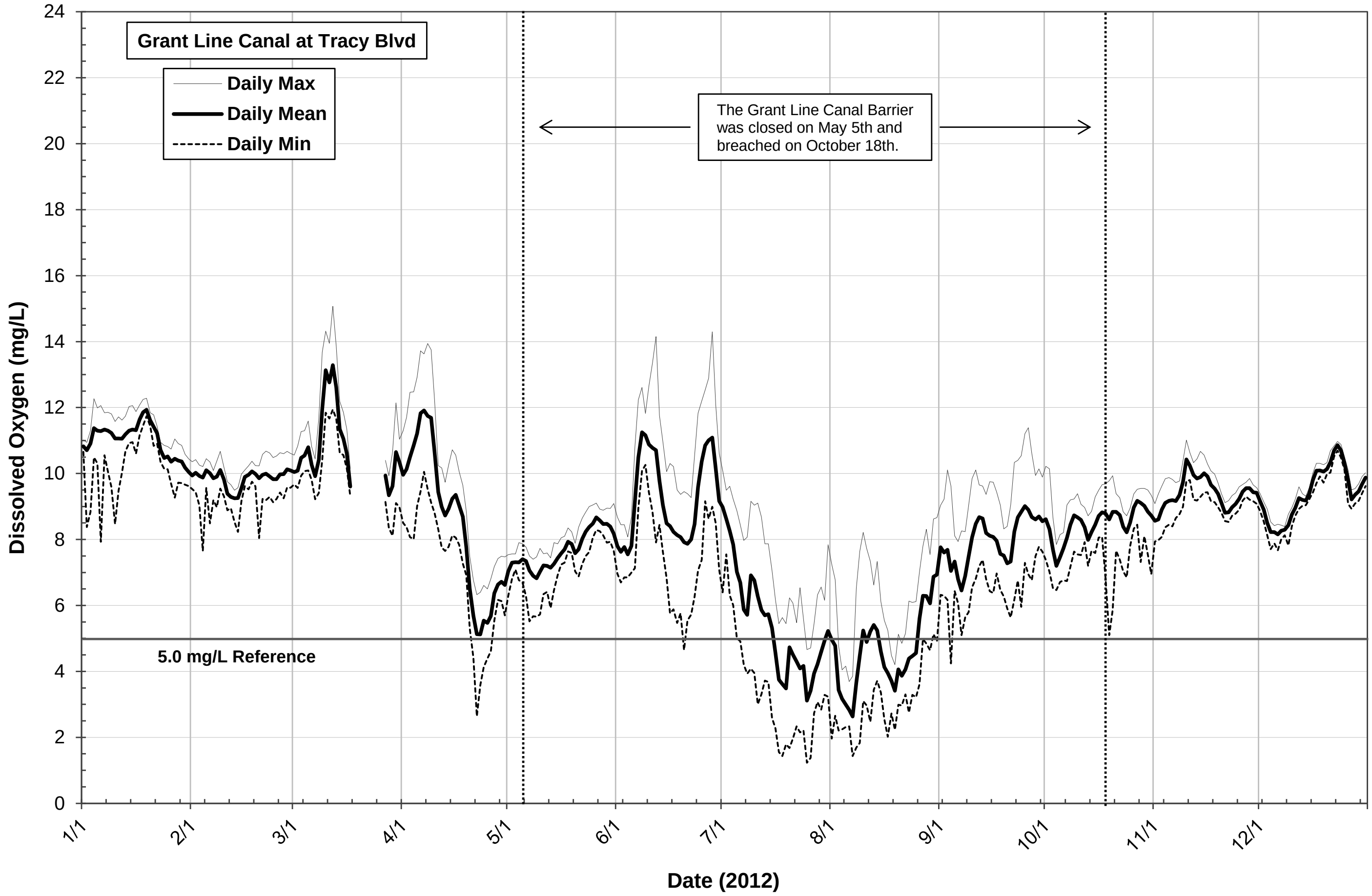


Figure 5-5: Daily Dissolved Oxygen time-series graphs for the Grant Line and Victoria Canal stations



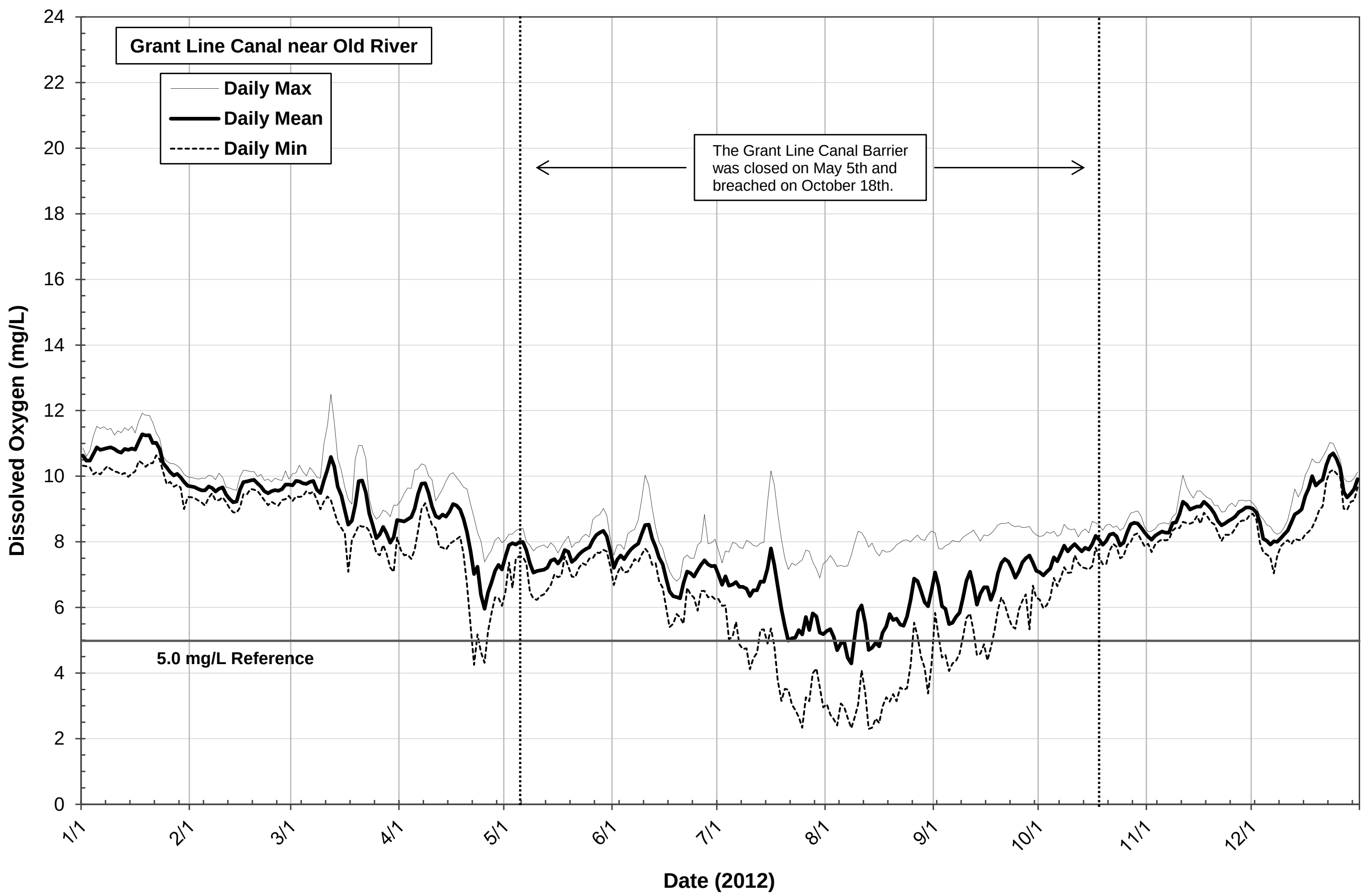


Figure 5-5: Daily Dissolved Oxygen time-series graphs for the Grant Line and Victoria Canal stations

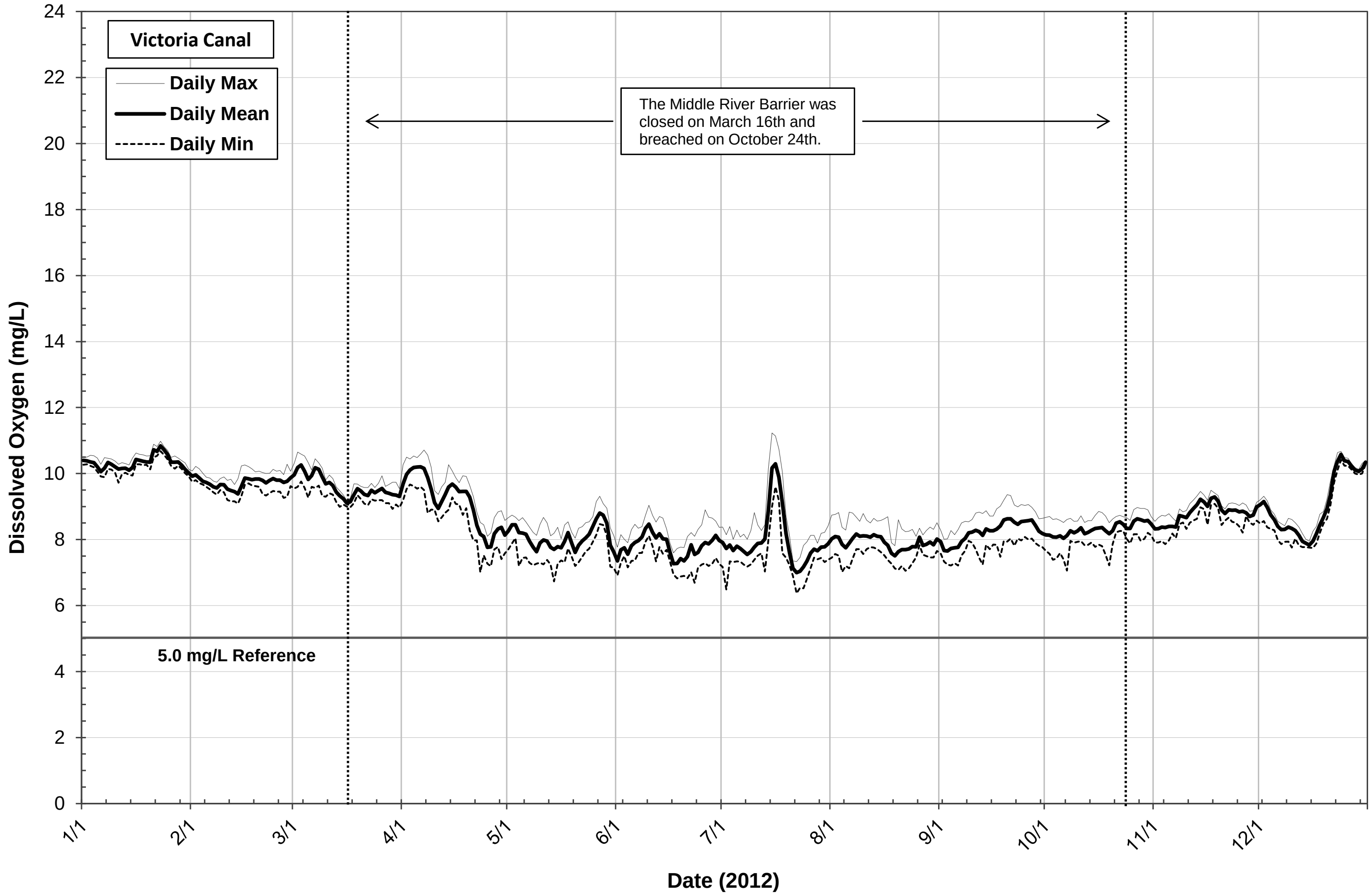
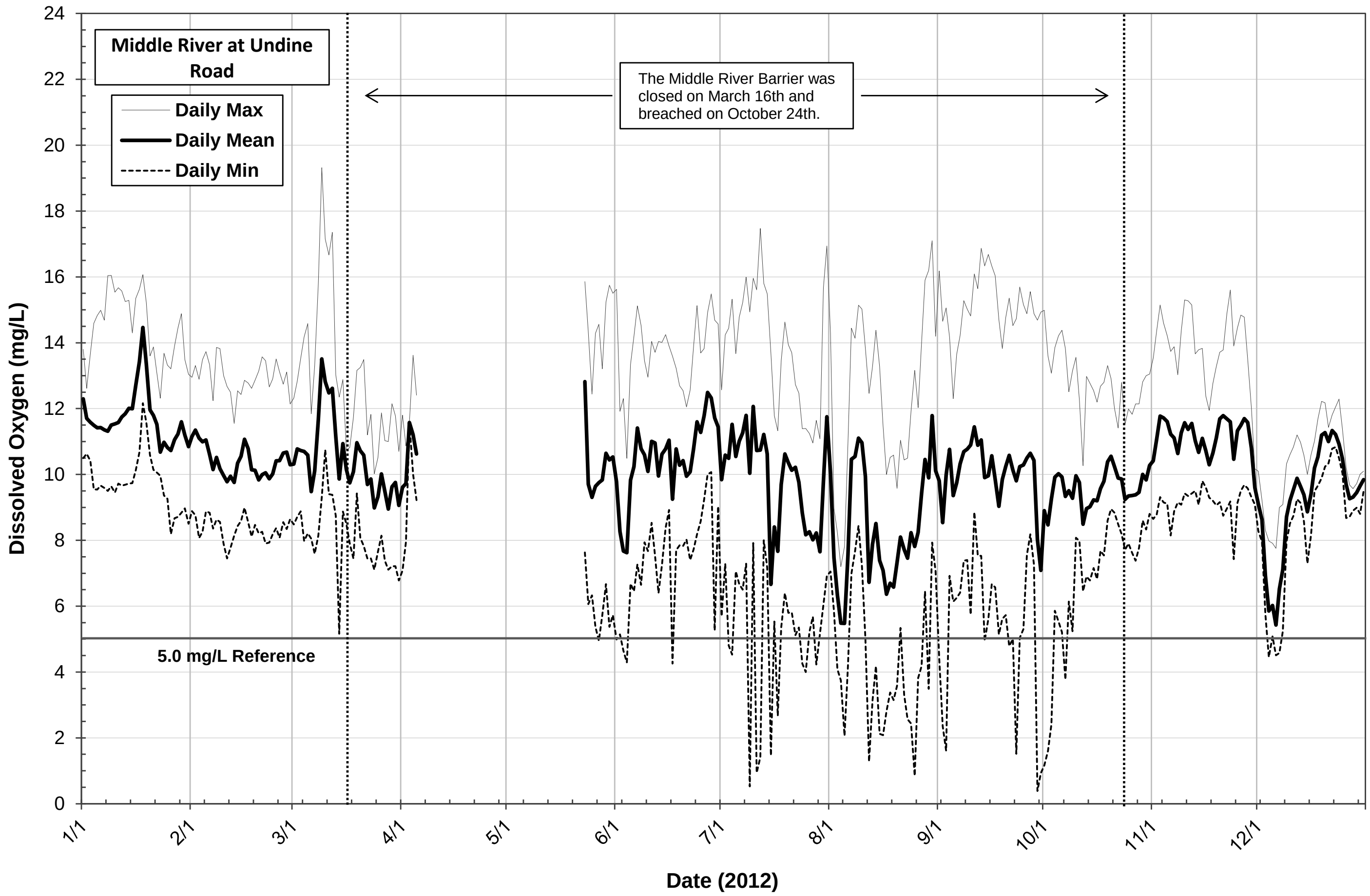


Figure 5-5: Daily Dissolved Oxygen time-series graphs for the Grant Line and Victoria Canal stations



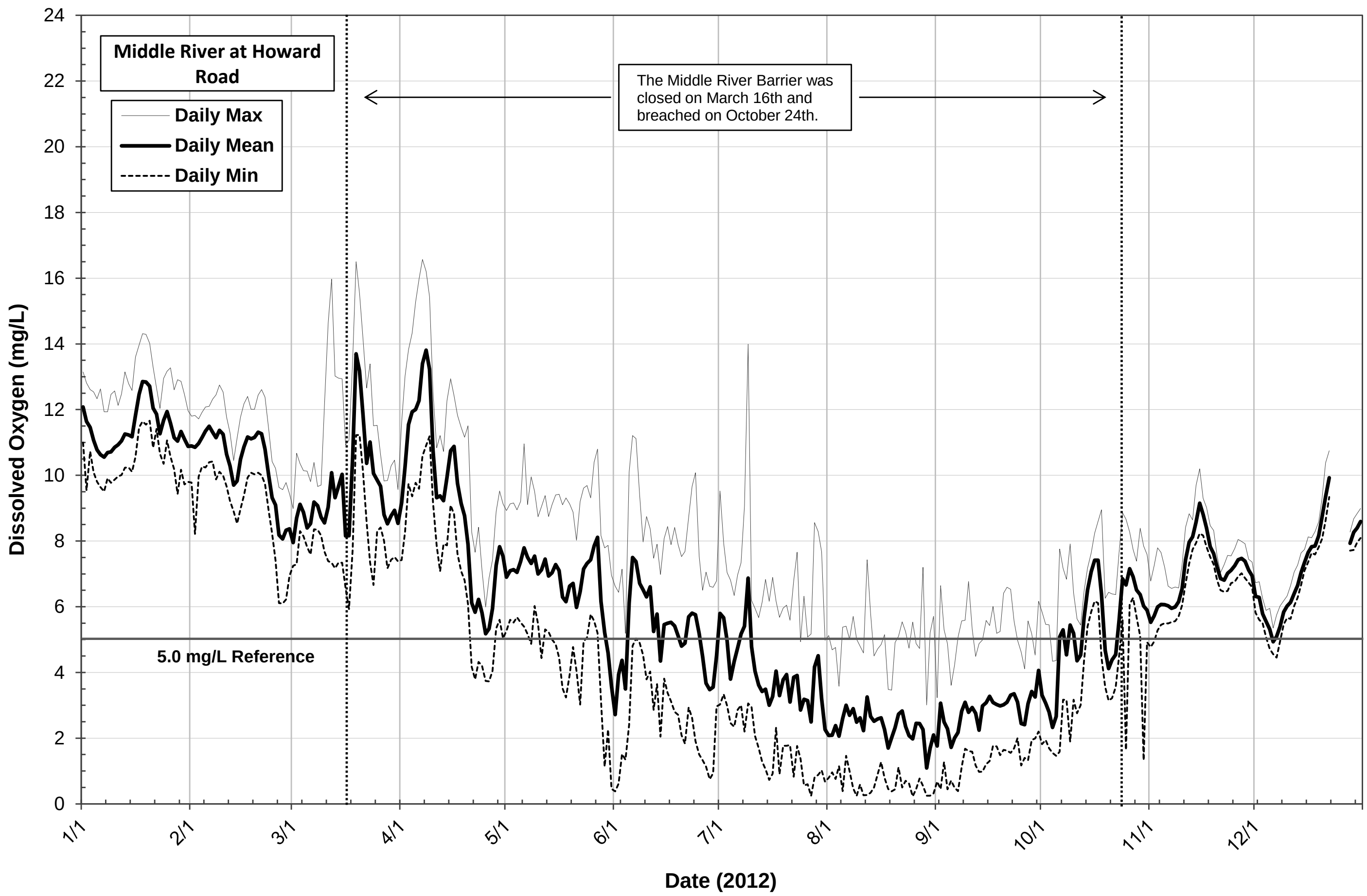
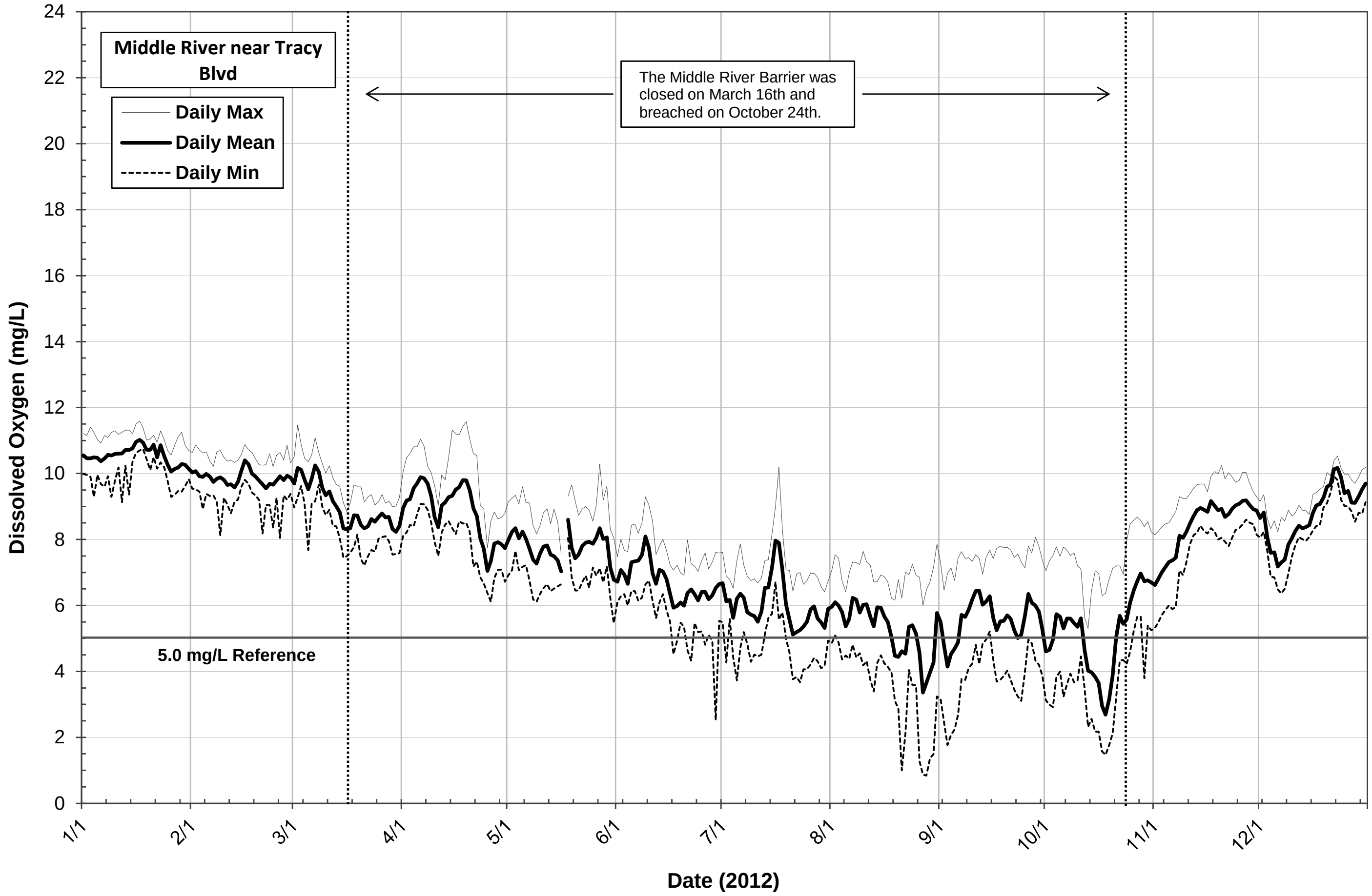


Figure 5-6: Daily Dissolved Oxygen time-series graphs for the Middle River stations



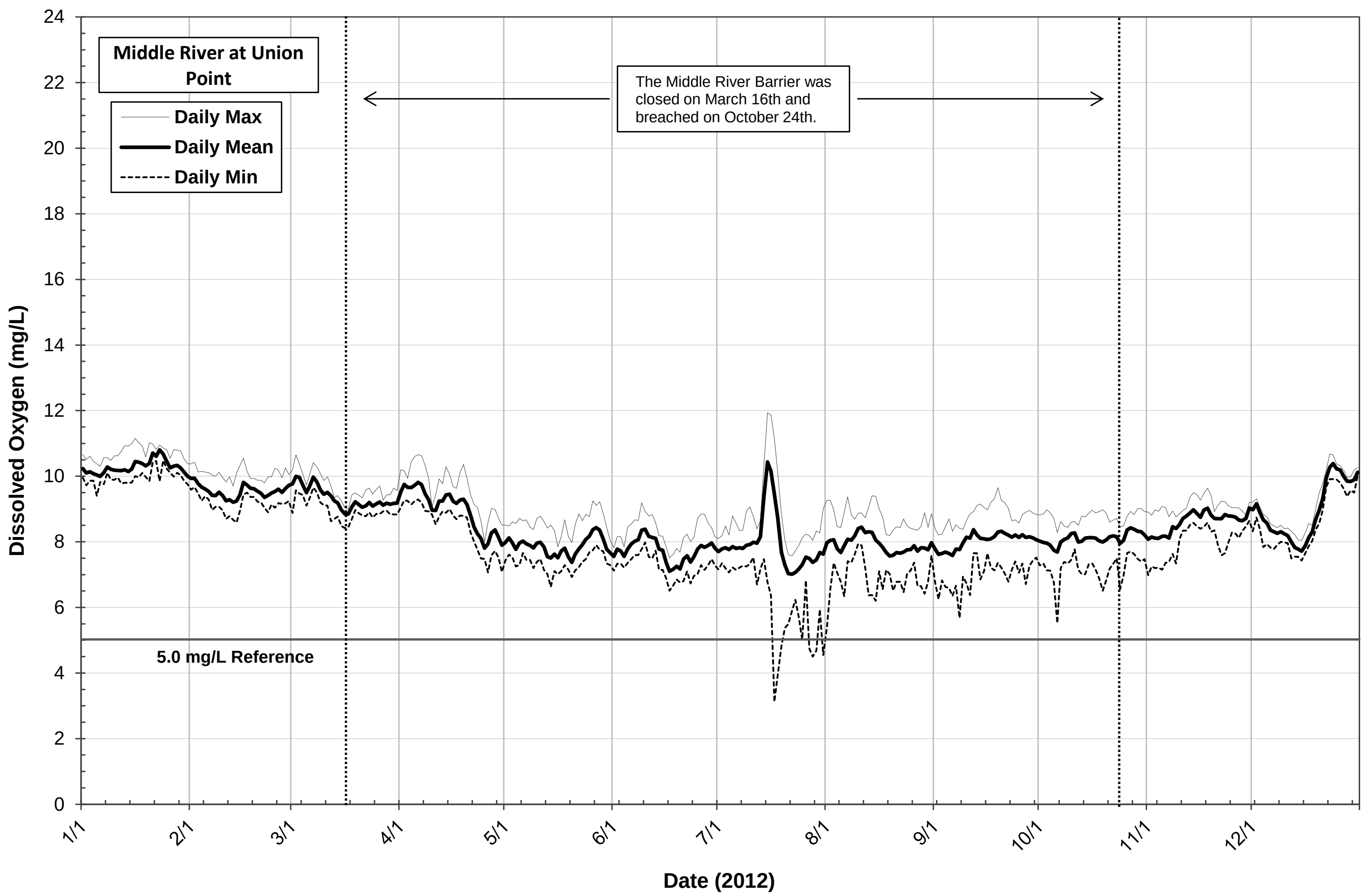
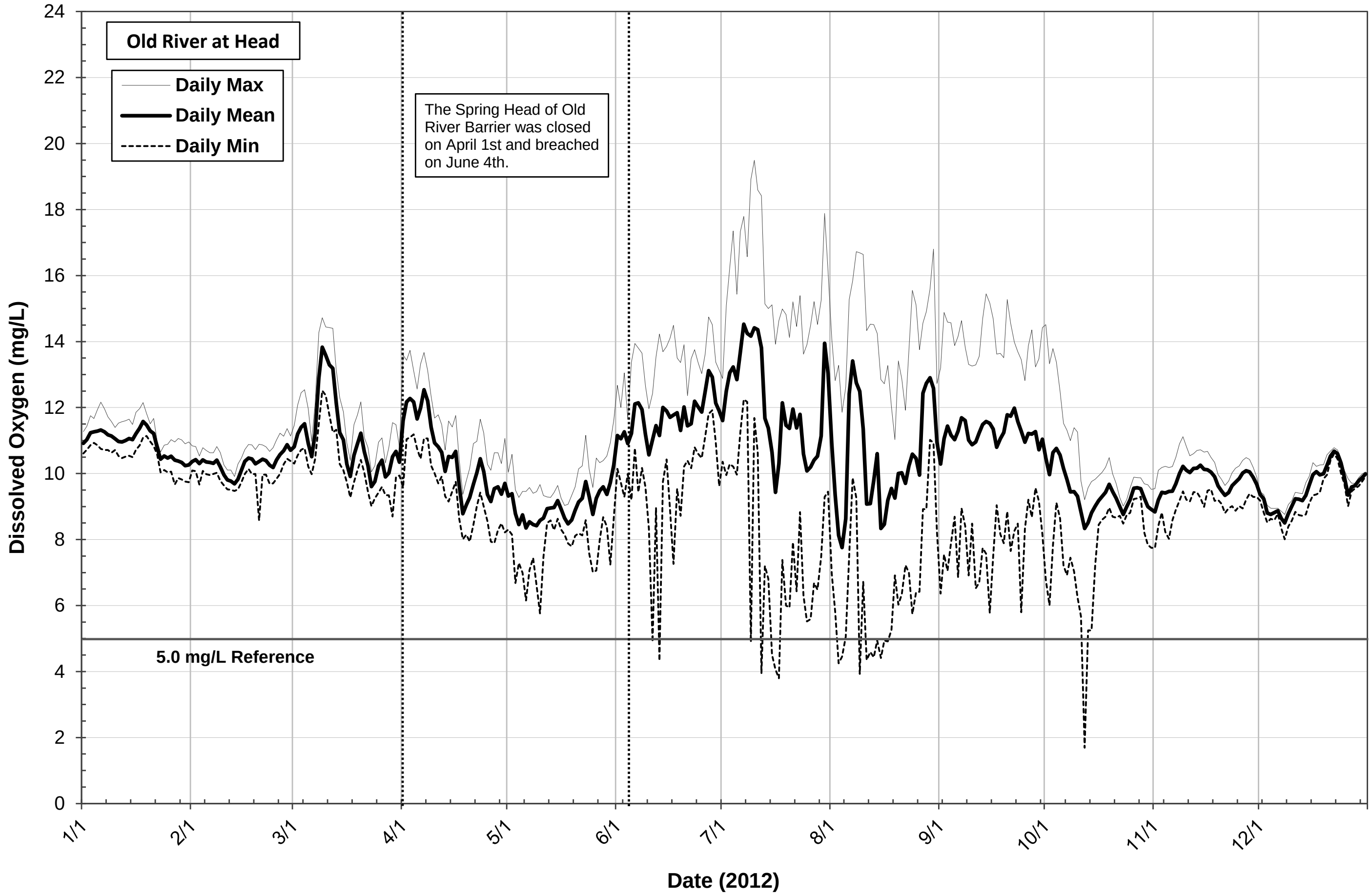


Figure 5-6: Daily Dissolved Oxygen time-series graphs for the Middle River stations



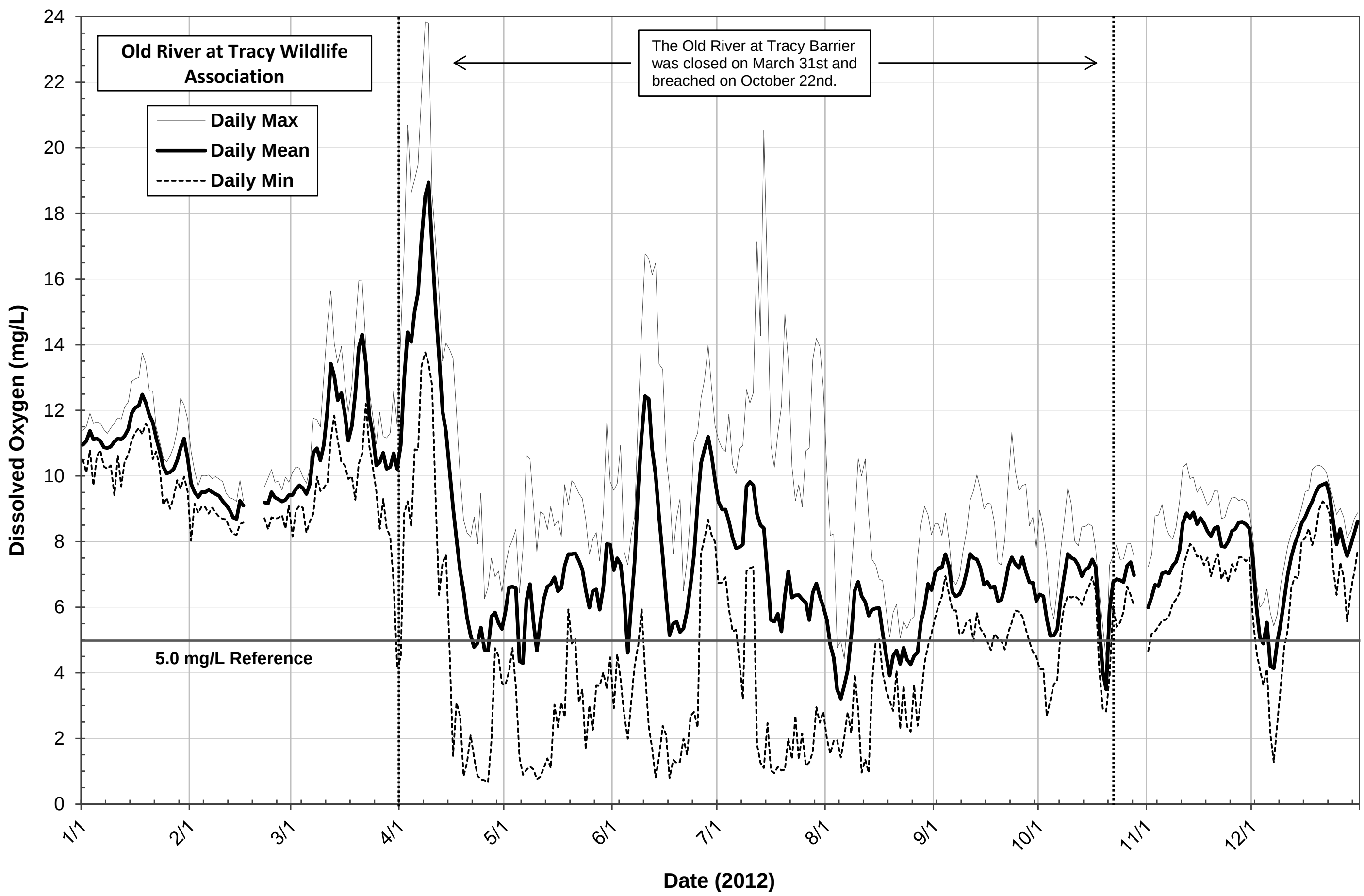
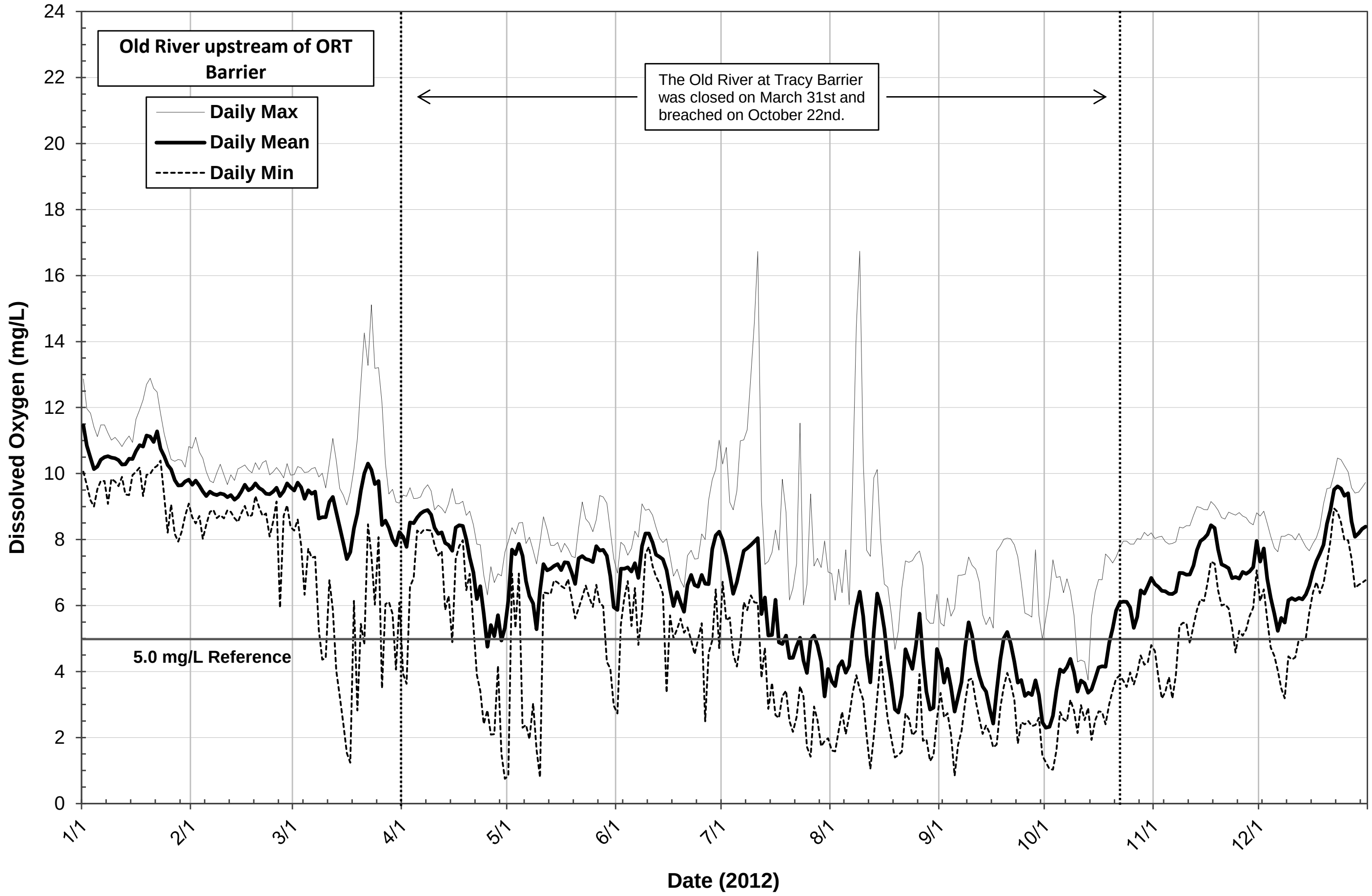


Figure 5-7: Daily Dissolved Oxygen time-series graphs for the Old River stations



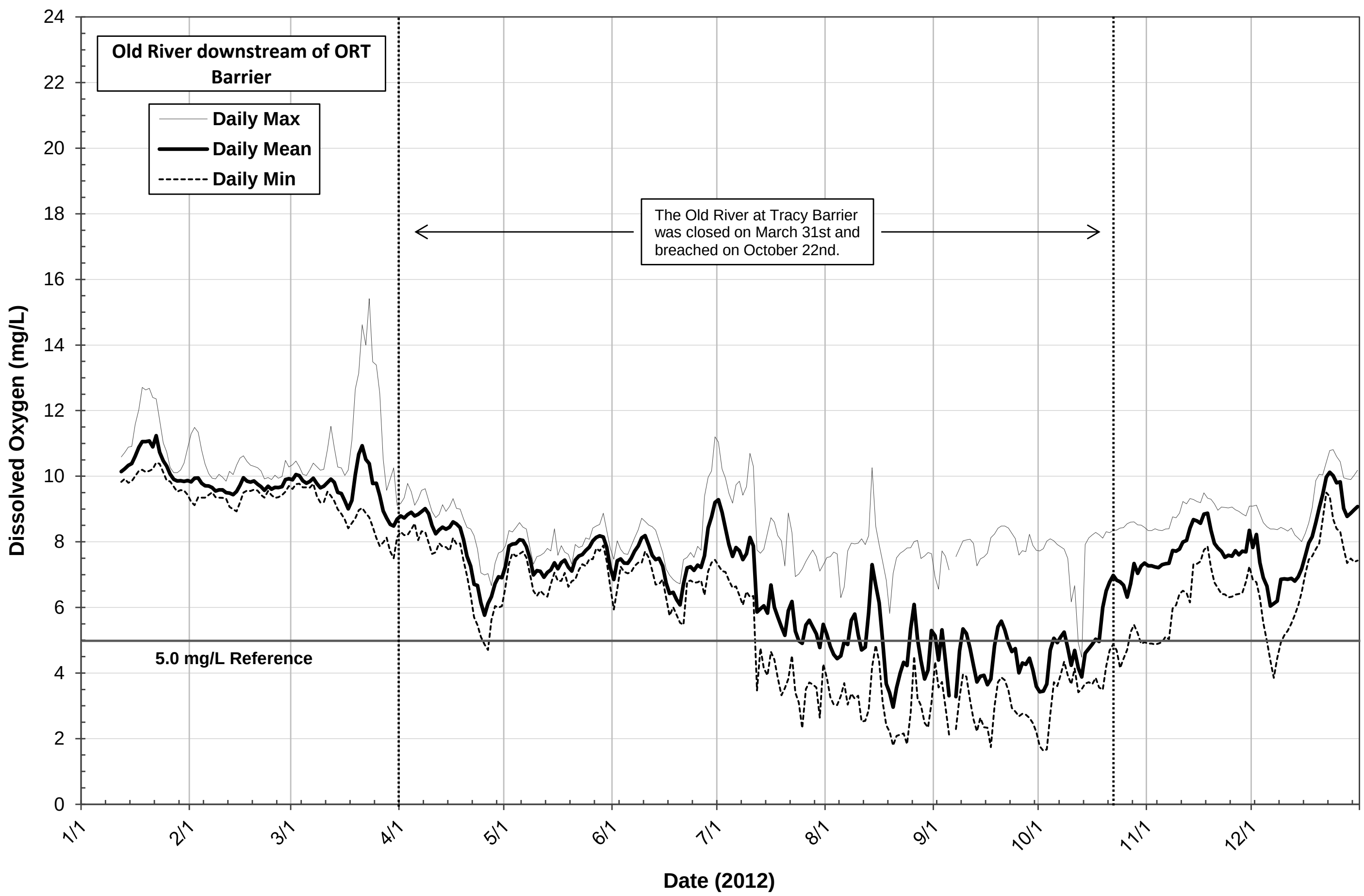
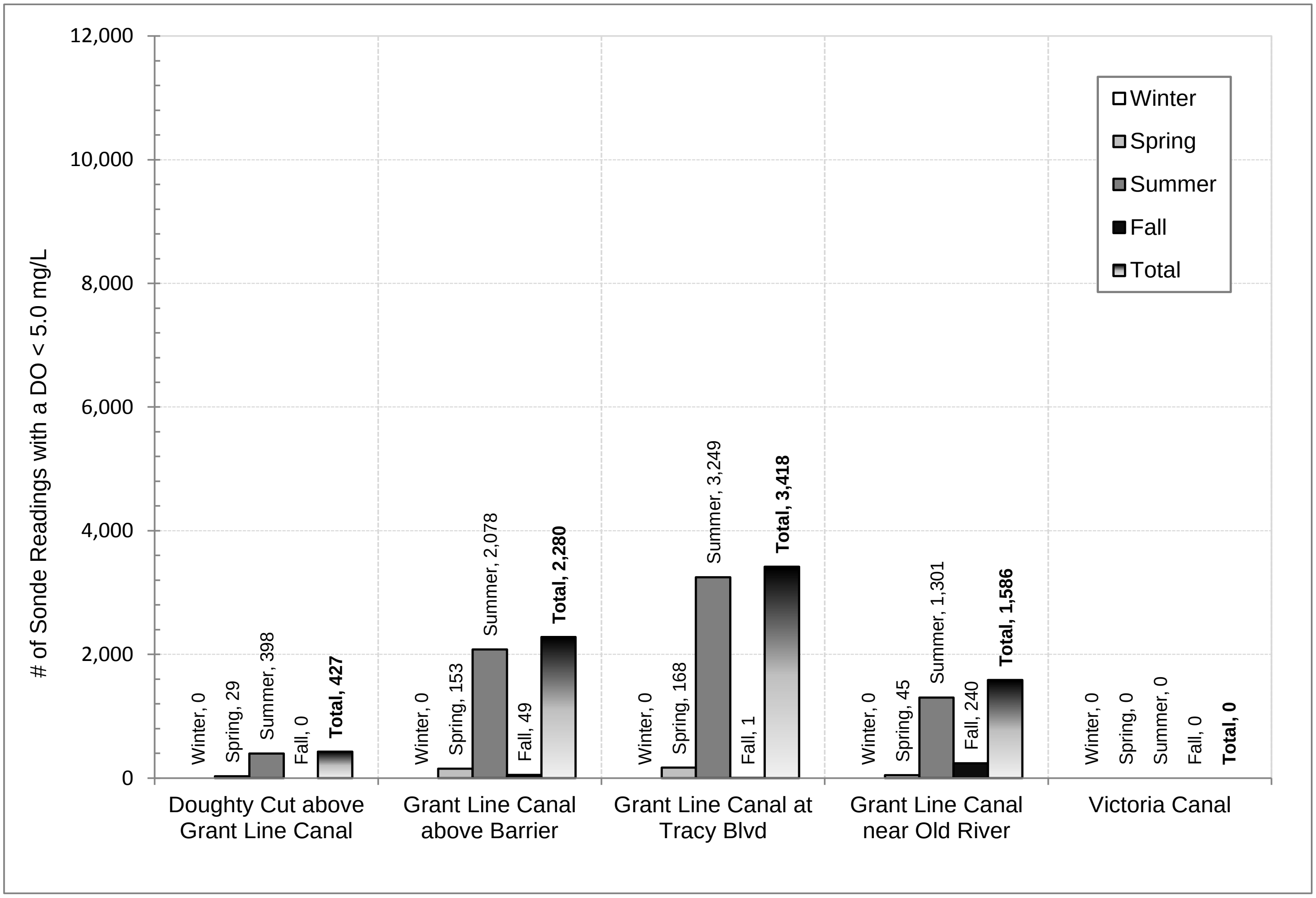


Figure 5-7: Daily Dissolved Oxygen time-series graphs for the Old River stations



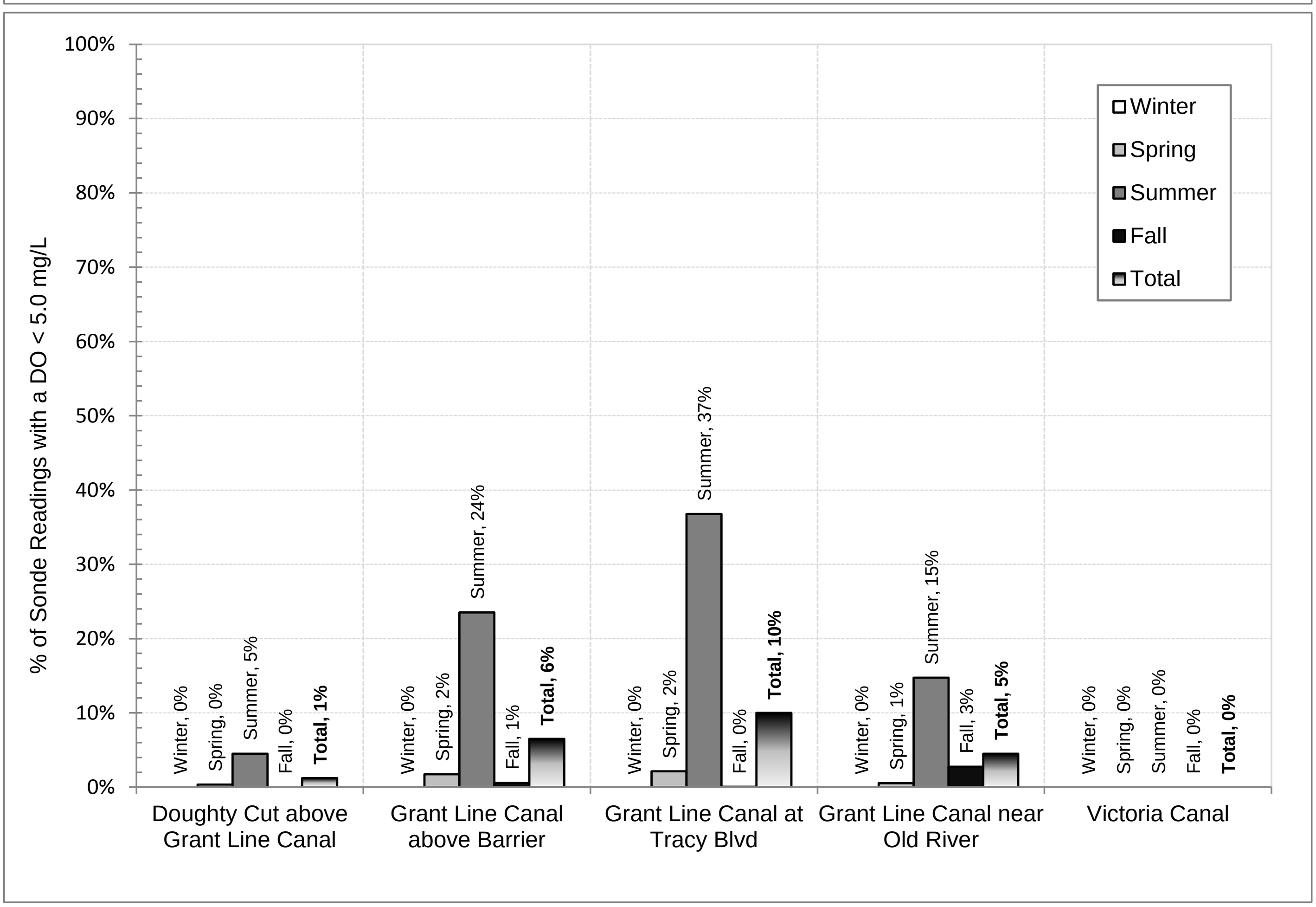


Figure 5-8: Dissolved Oxygen Standard Exceedences for the Grant Line and Victoria Canal stations

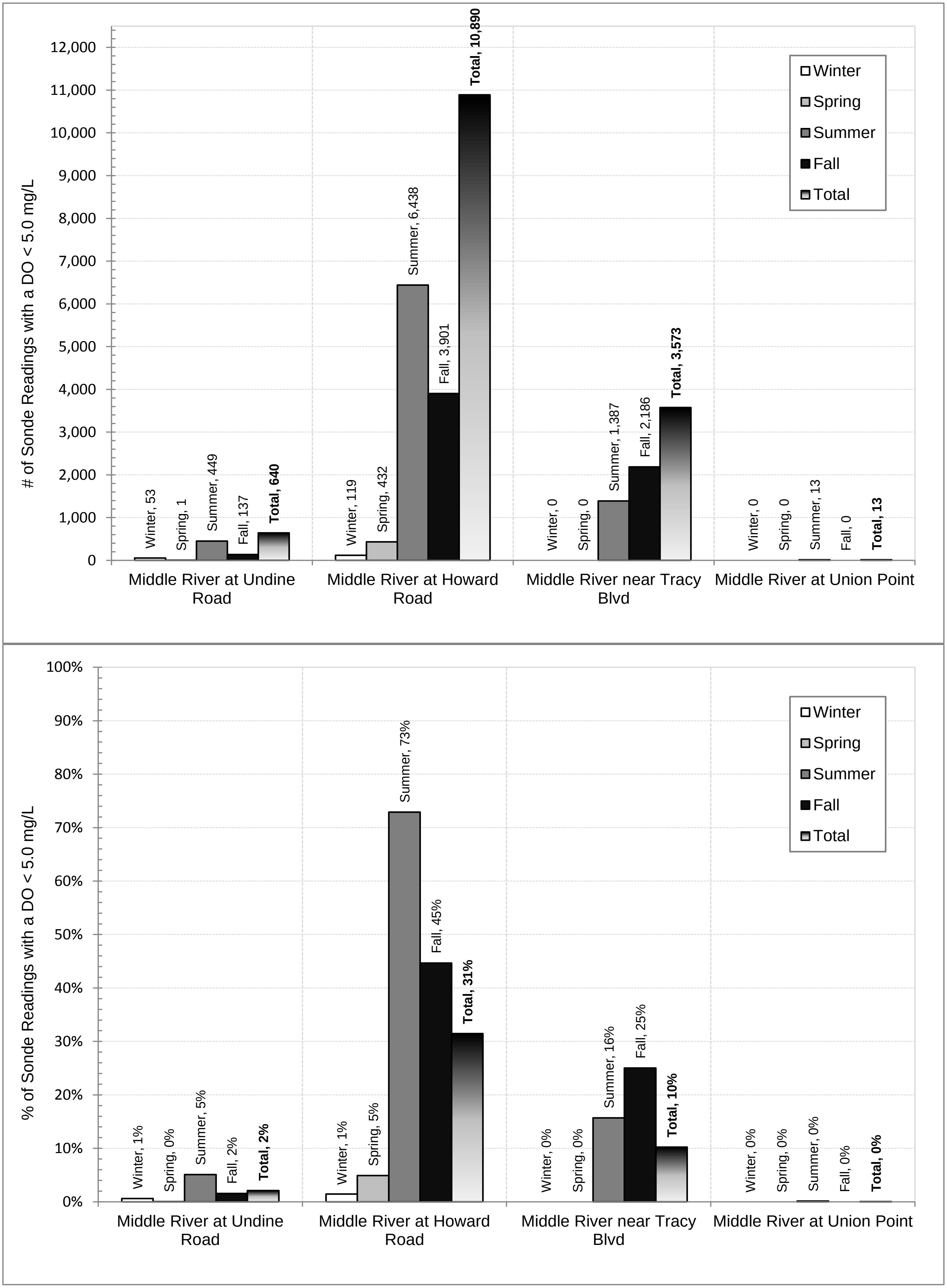


Figure 5-9: Dissolved Oxygen Standard Exceedences for the Middle River stations

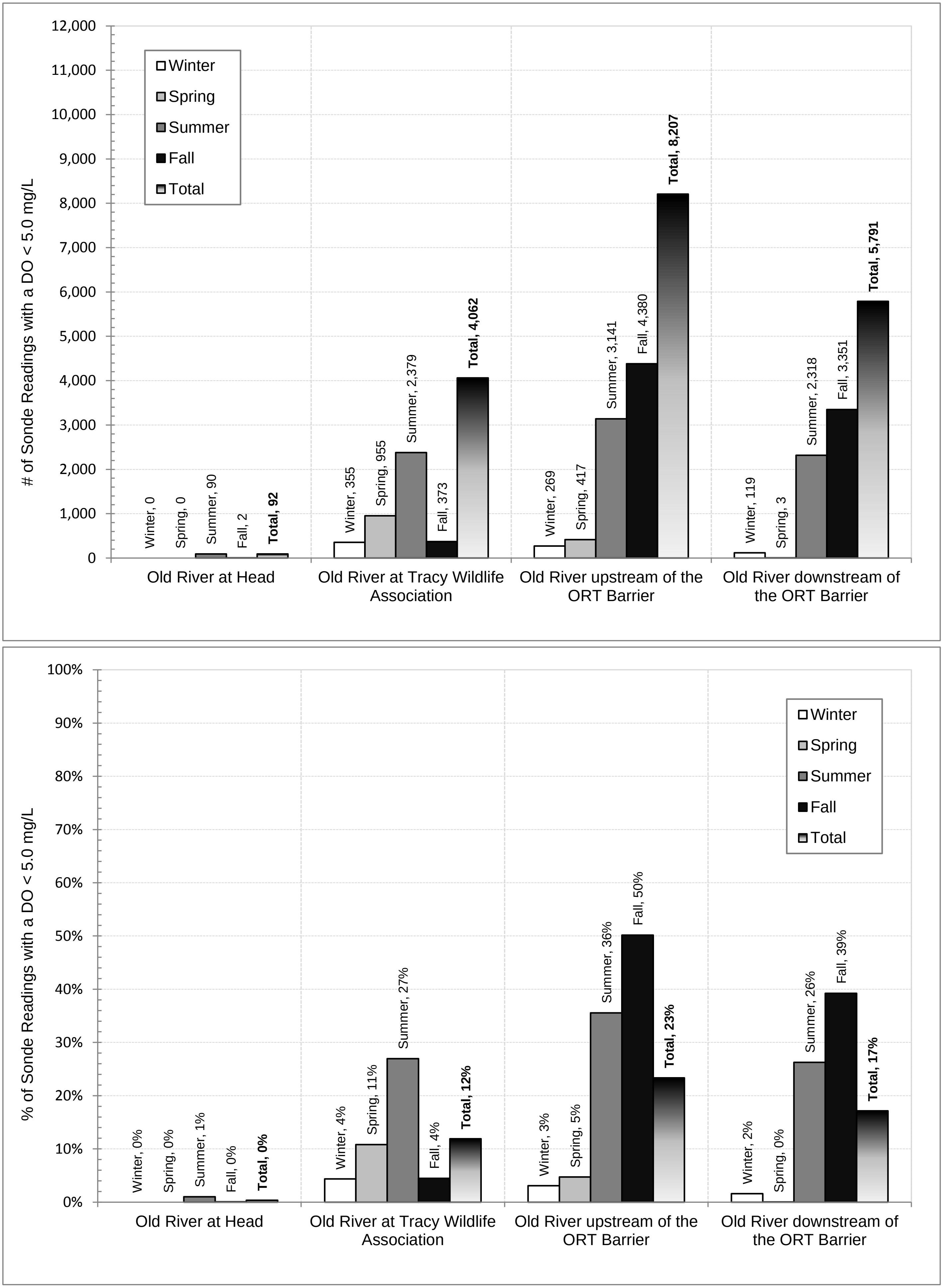


Figure 5-10: Dissolved Oxygen Standard Exceedences for the Old River stations

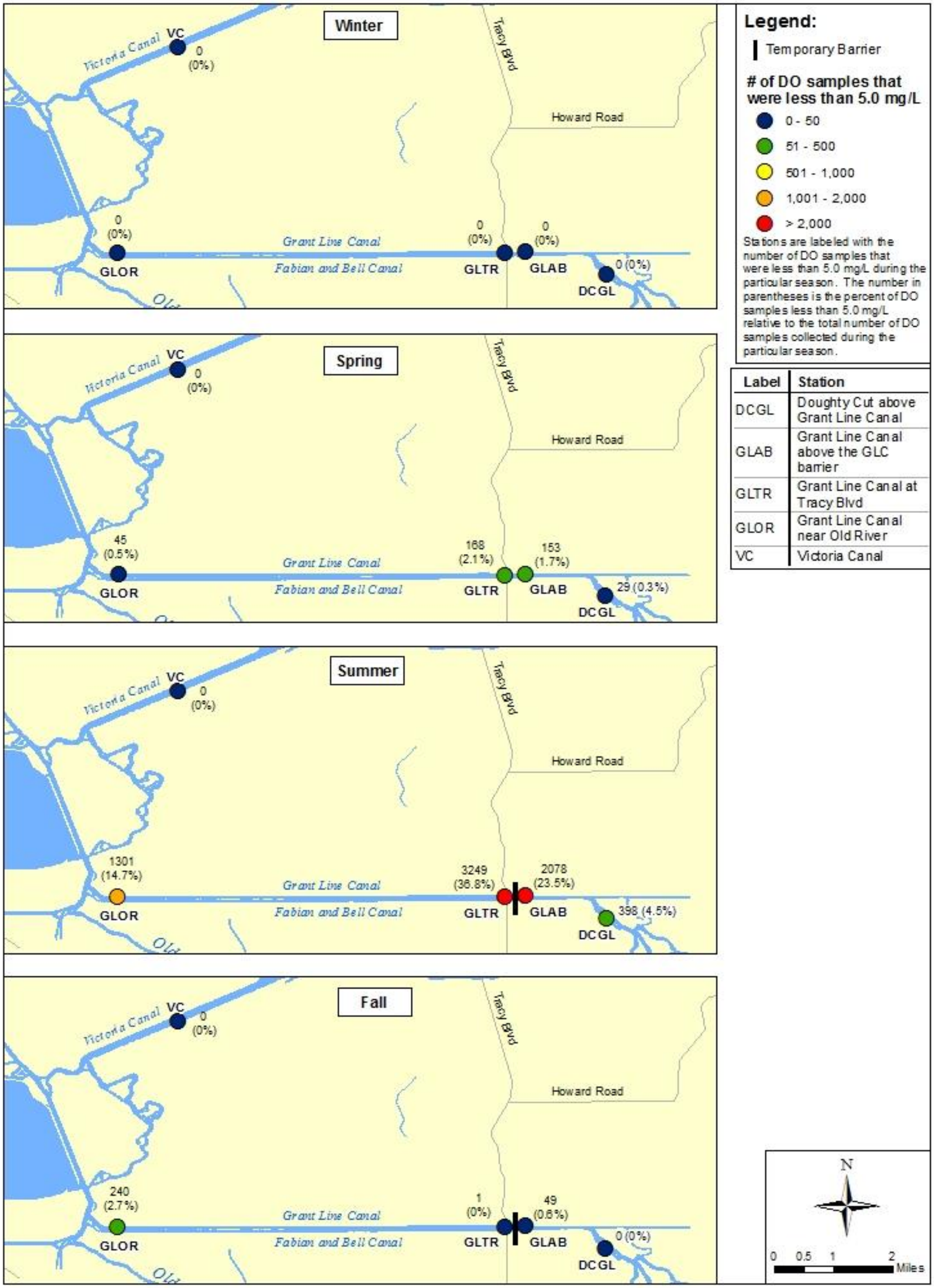


Figure 5-11: Map of Dissolved Oxygen Standard Exceedences for the Grant Line and Victoria Canal stations

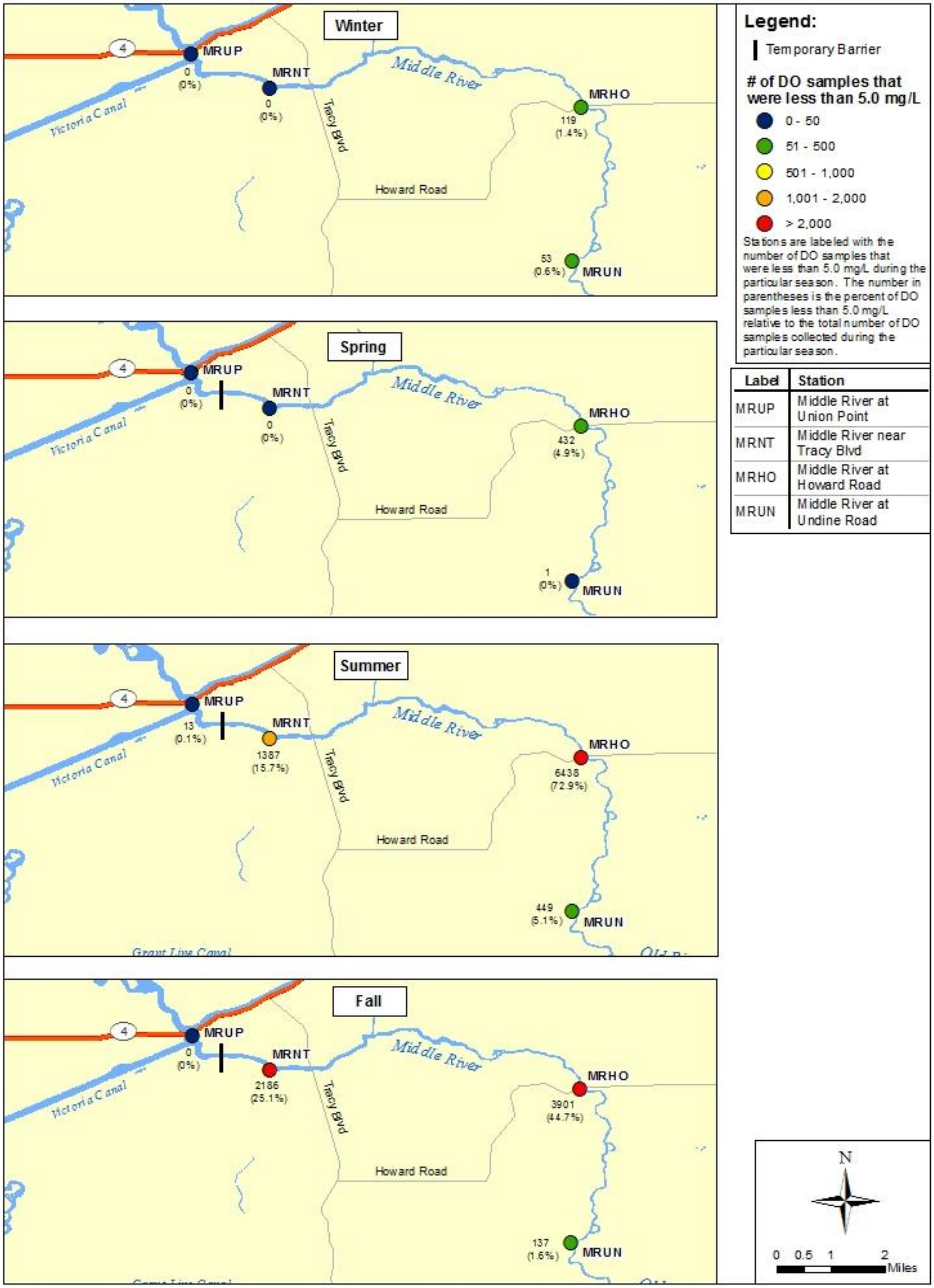


Figure 5-12: Map of Dissolved Oxygen Standard Exceedences for the Middle River stations

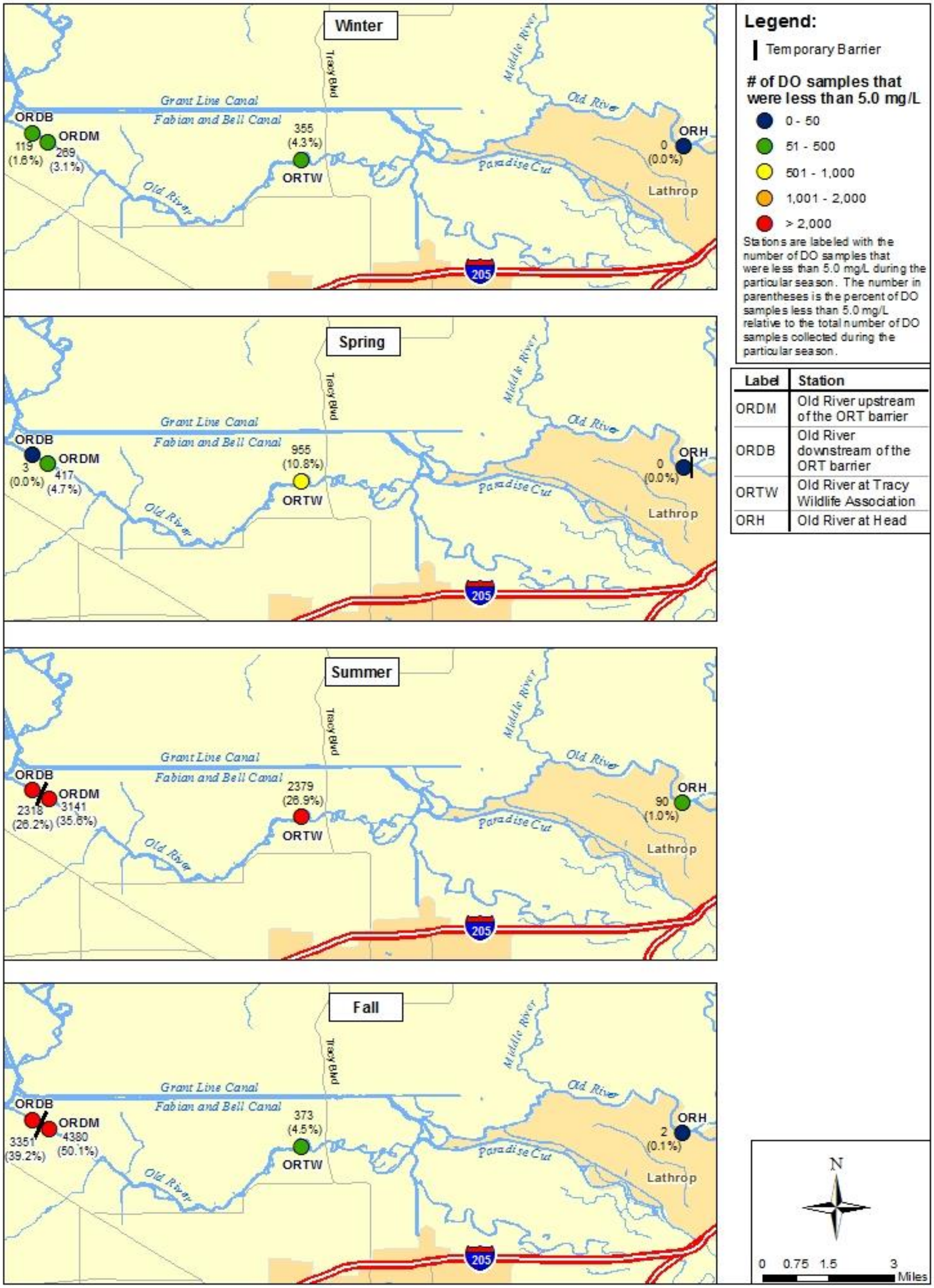


Figure 5-13: Map of Dissolved Oxygen Standard Exceedences for the Old River stations

pH

pH is a measure of the hydrogen ion concentration [H^+] of a solution. pH values range from 1 to 14 with values less than 7 considered acidic and values greater than 7 considered basic. Since the pH scale is logarithmic; a pH value of 7 is ten times greater than a pH value of 6 and one hundred times greater than a value of 5. Natural waters usually have pH values in the range of 4 to 9, and most are slightly basic (APHA, 2005). Algal photosynthesis occurring in the water column can affect pH values. The process of photosynthesis consumes CO_2 from the water. Less CO_2 in the water decreases carbonic acid which makes the water more alkaline and increases the pH.

A maximum pH of 9.89 was recorded on July 2nd at Old River at Head and a minimum of 6.54 was recorded on August 26th at Grant Line Canal at Tracy Blvd (Tables 5-3 to 5-6). Figures 5-14, 5-15, and 5-16 illustrate the daily maximums, minimums, and averages for the Grant Line and Victoria Canal, Middle River, and Old River stations, respectively.

Typically, at the South Delta stations there is a noticeable increase in pH values during the spring months that is associated with increasing rates of photosynthesis; this was observed at the Grant Line Canal and Old River Stations, but not as noticeable at the Middle River Stations (Figures 5-14 to 5-16). Chlorophyll *a* concentrations increased during the end of March and April at most South Delta stations, except at Victoria Canal, Middle River near Tracy Blvd, and Middle River at Union Point (Figures 4-29, 5-30, and 5-31). Monthly average pH values during the spring (March – May) ranged from 7.44 in May at Middle River at Howard Road to 8.21 in March at Old River at Tracy Wildlife Association (Tables 5-3 to 5-6).

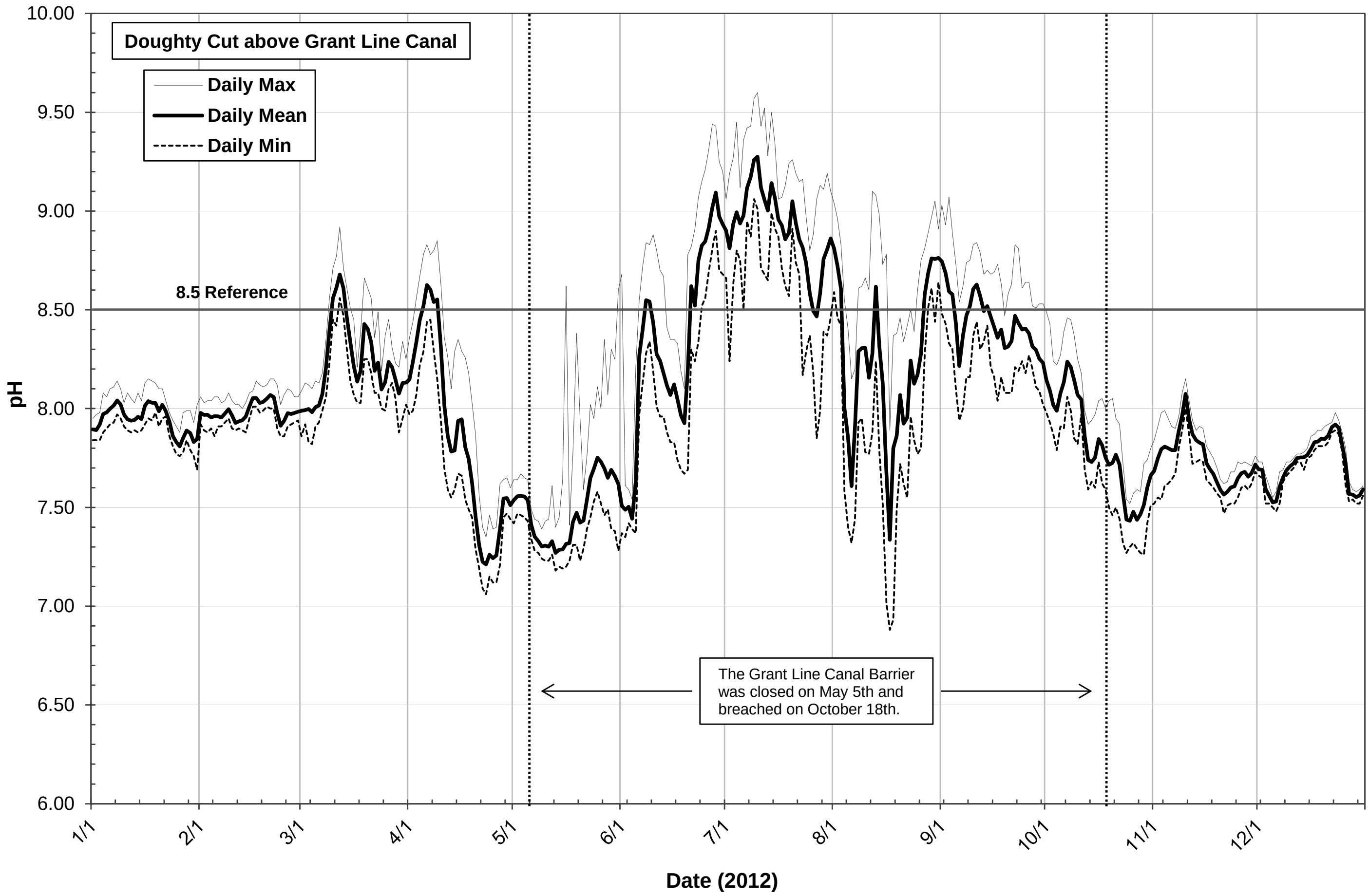
At some of the South Delta stations (Old River at Tracy Wildlife Association, Old River at Head, Middle River at Undine Road, Grant Line Canal at Tracy at Tracy Blvd, Grant Line Canal above the Grant Line Canal barrier, and Doughty Cut above Grant Line Canal Barrier) pH values were higher and more variable from mid-June to mid-October. Chlorophyll a concentrations were also higher at those stations during summer and early fall (Figures 5-29, 5-30, and 5-31). Average monthly chlorophyll *a* concentrations and pH values were highest in July for each of those stations (Tables 5-3 to 5-6). Monthly average pH values during the summer and early fall (June – October) ranged from 6.86 in August at Middle River at Howard Road to 9.05 in July at Old River at Head.

At most of the stations, the pH values trended downward from September through December 2012 (Figures 5-14 to 5-16). Similar to the trend in pH values, chlorophyll *a* concentrations, at most of the stations, began to decrease during the same time period (Figures 5-29, 5-30, and 5-31). During November and December of 2012, monthly average pH values ranged from 7.18 at Howard Road to 8.07 at Middle River at Undine Road (Tables 5-3 to 5-6).

Water Quality Standard Exceedences:

As discussed in the Methods and Results section, the established pH criteria is 8.50 units; therefore, staff considered any pH sample of reliable data quality greater than 8.50 as exceeding the standard. Figures 5-17, 5-18, and 5-19 illustrate the number of pH readings with concentrations greater than 8.50 for each season and the overall total for the 2012 monitoring period for the Grant Line and Victoria Canal, Middle River, and Old River stations, respectively. In addition, the figures show the percent of sonde samples exceeding the pH standard relative to the total number of samples collected. Figures 5-20, 5-21, and 5-22 provide the exceedence information in a map format allowing for the observation of geographical relationships.

The station with the most pH exceedences during 2012 was Old River at Head with a total of 9,912 (28% of the total number of samples). The majority of the stations had more pH exceedences during summer and fall. The Middle River near Tracy Blvd and Grant Line Canal near Old River stations had the least amount of pH exceedences, with less than 1% of the total sample sonde readings exceeding 8.5.



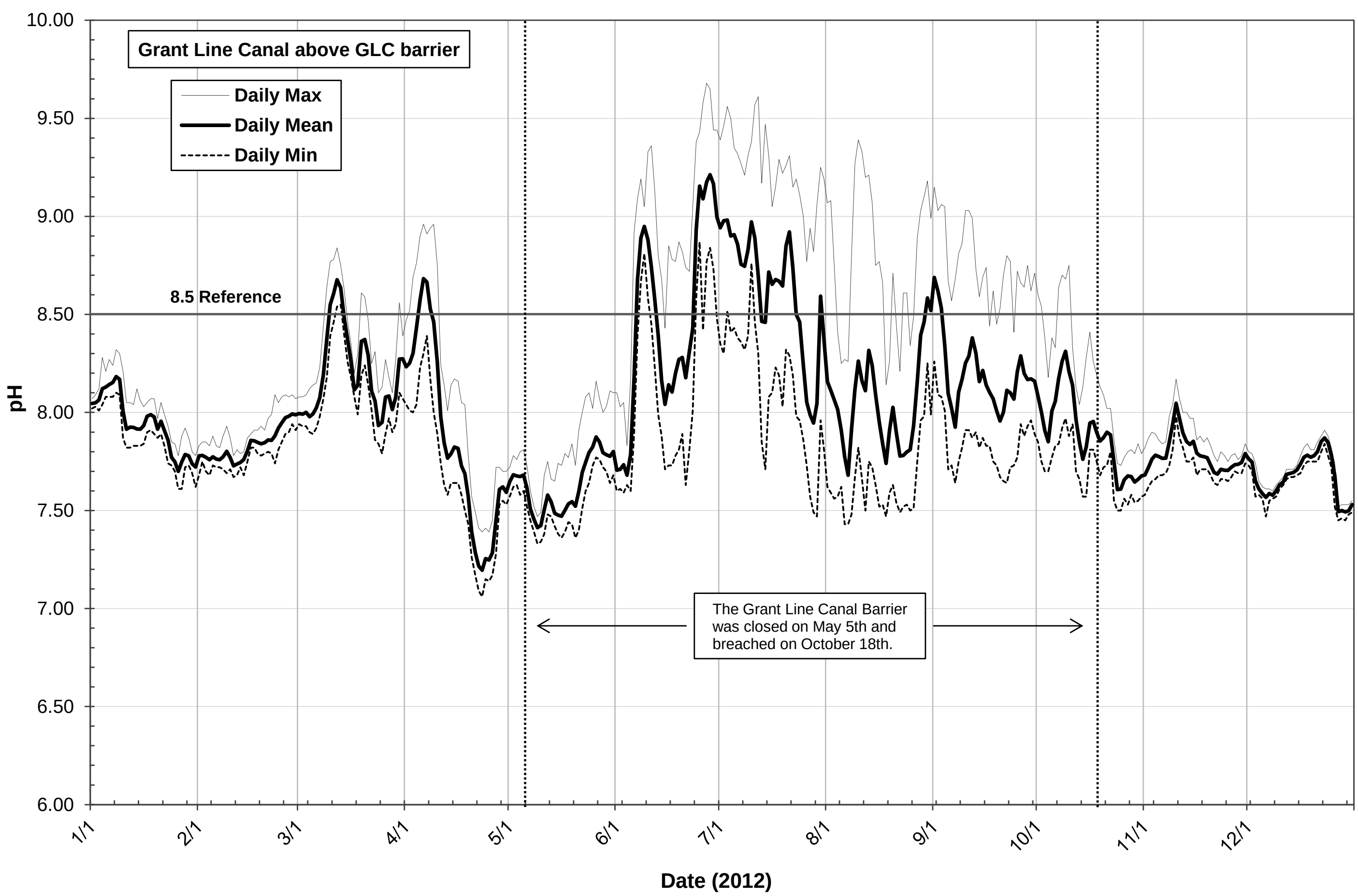


Figure 5-14: Daily pH time-series graphs for the Grant Line and Victoria Canal stations

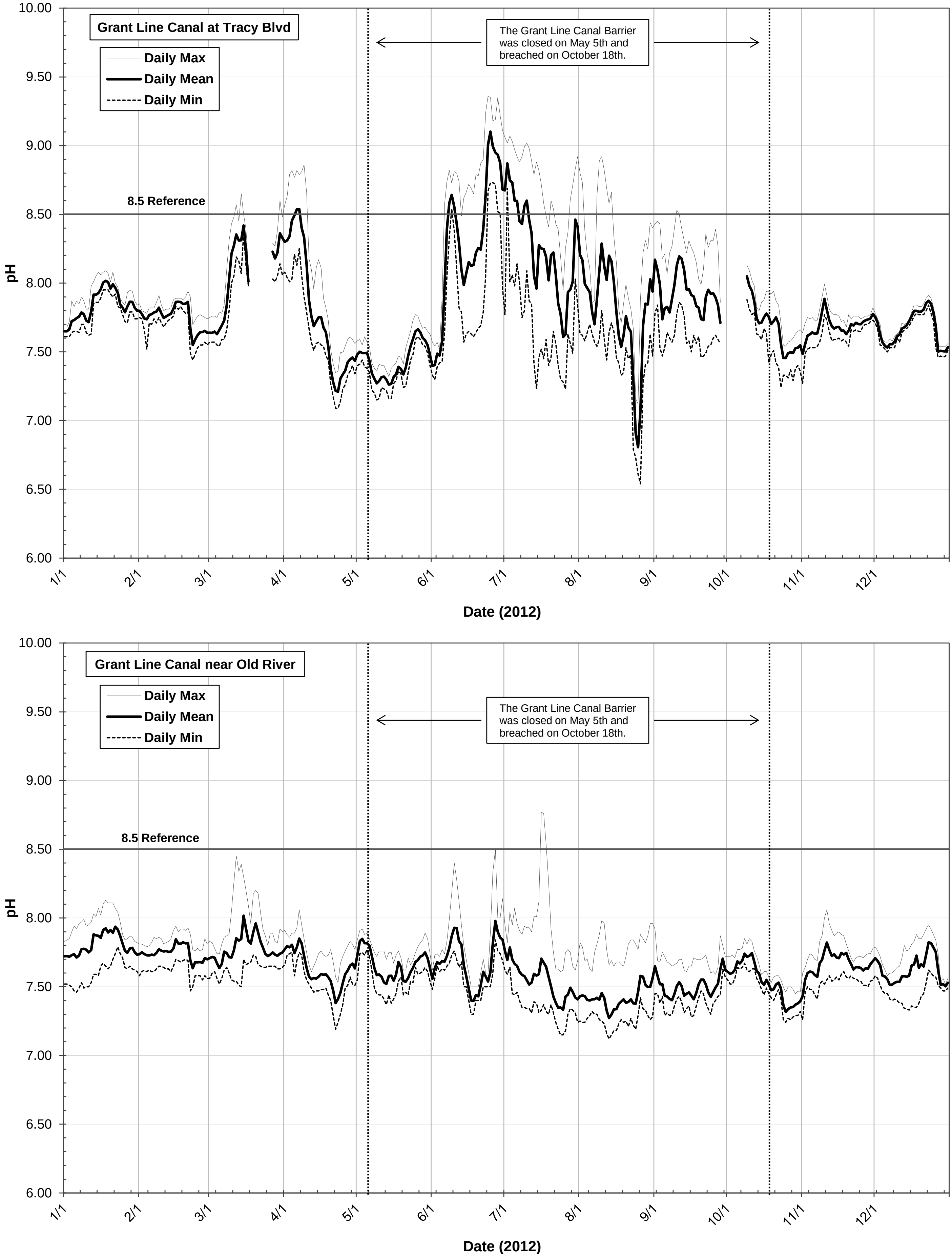


Figure 5-14: Daily pH time-series graphs for the Grant Line and Victoria Canal stations

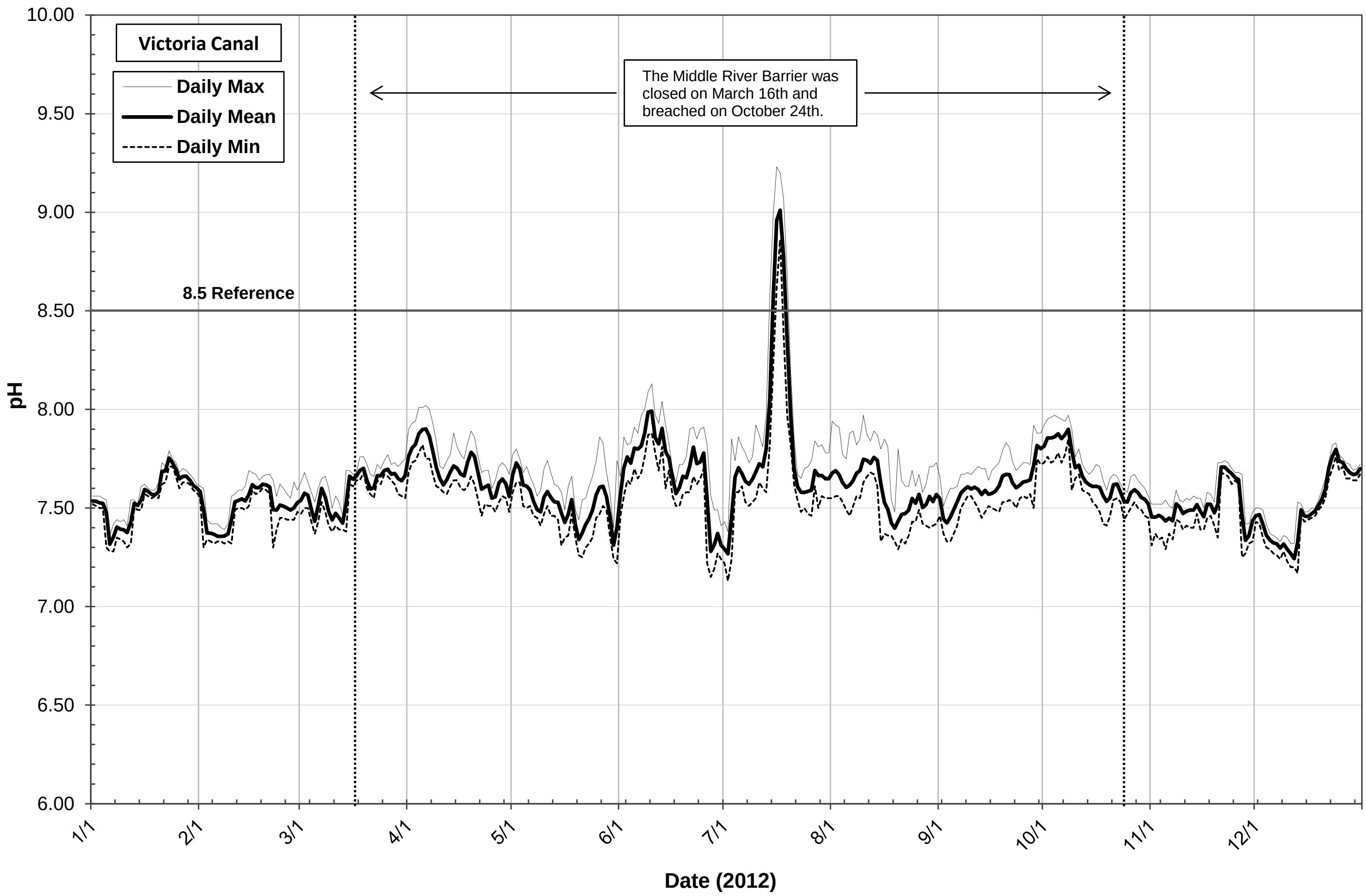
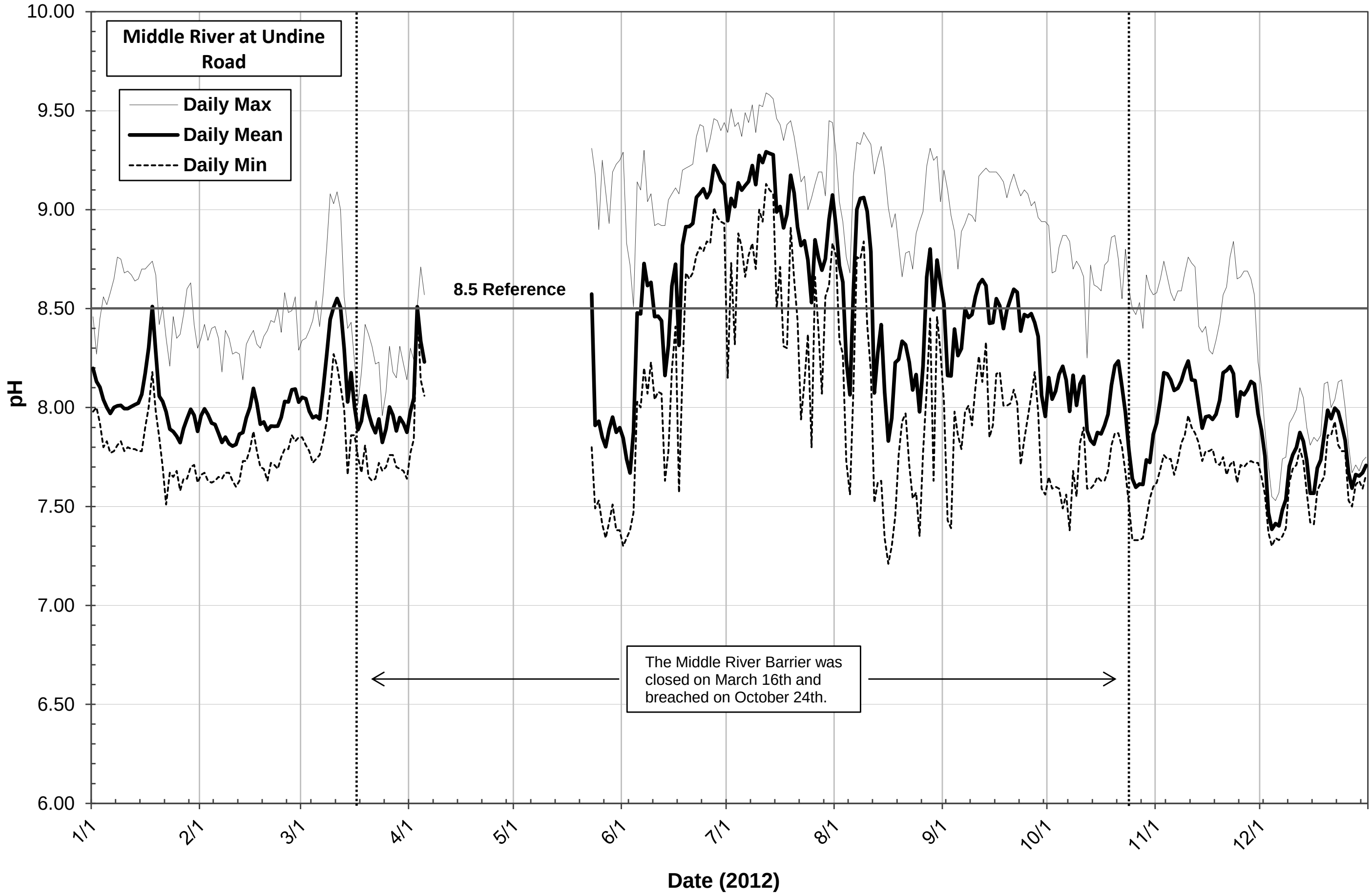


Figure 5-14: Daily pH time-series graphs for the Grant Line and Victoria Canal stations



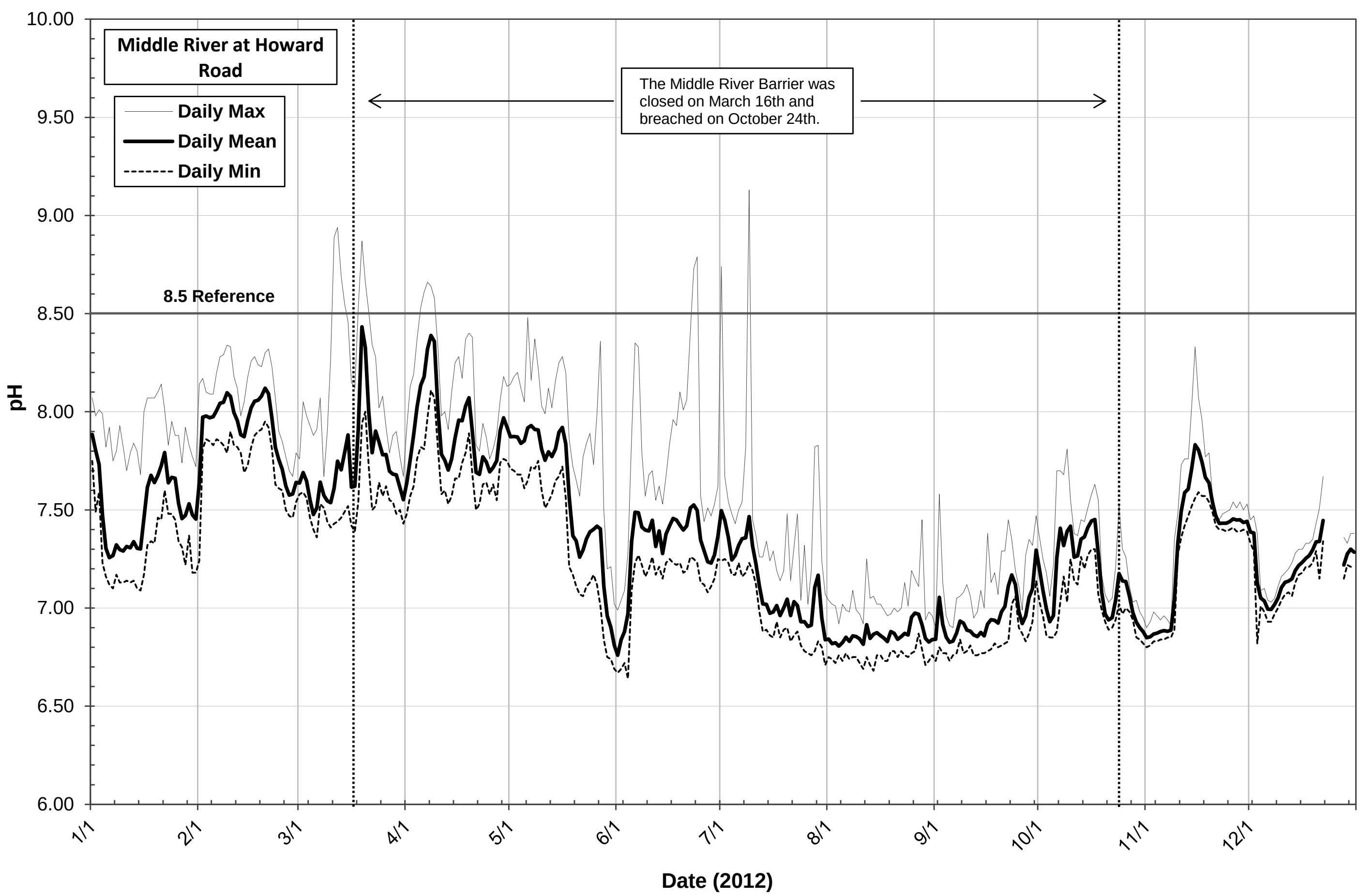
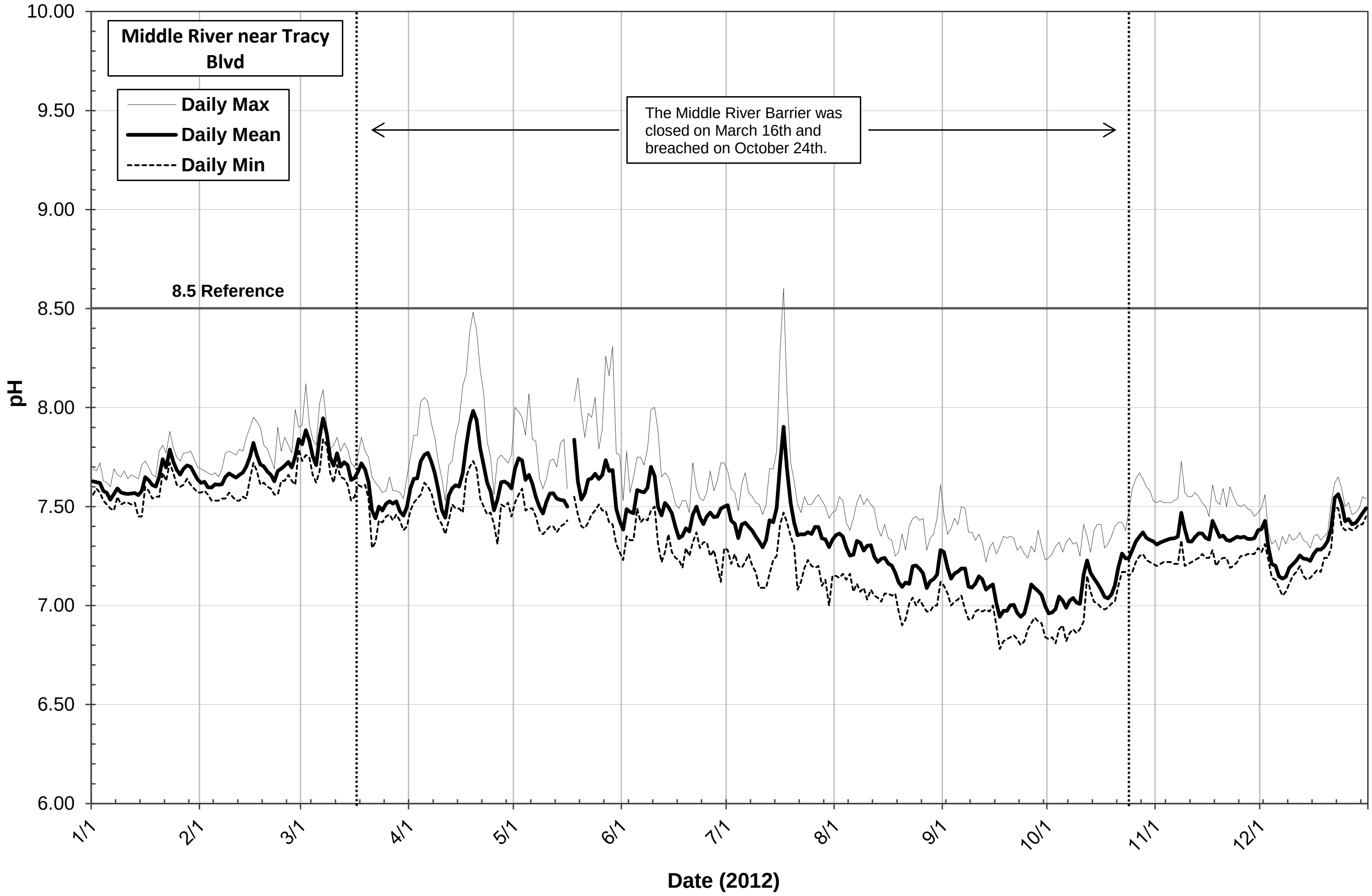


Figure 5-15: Daily pH time-series graphs for the Middle River stations



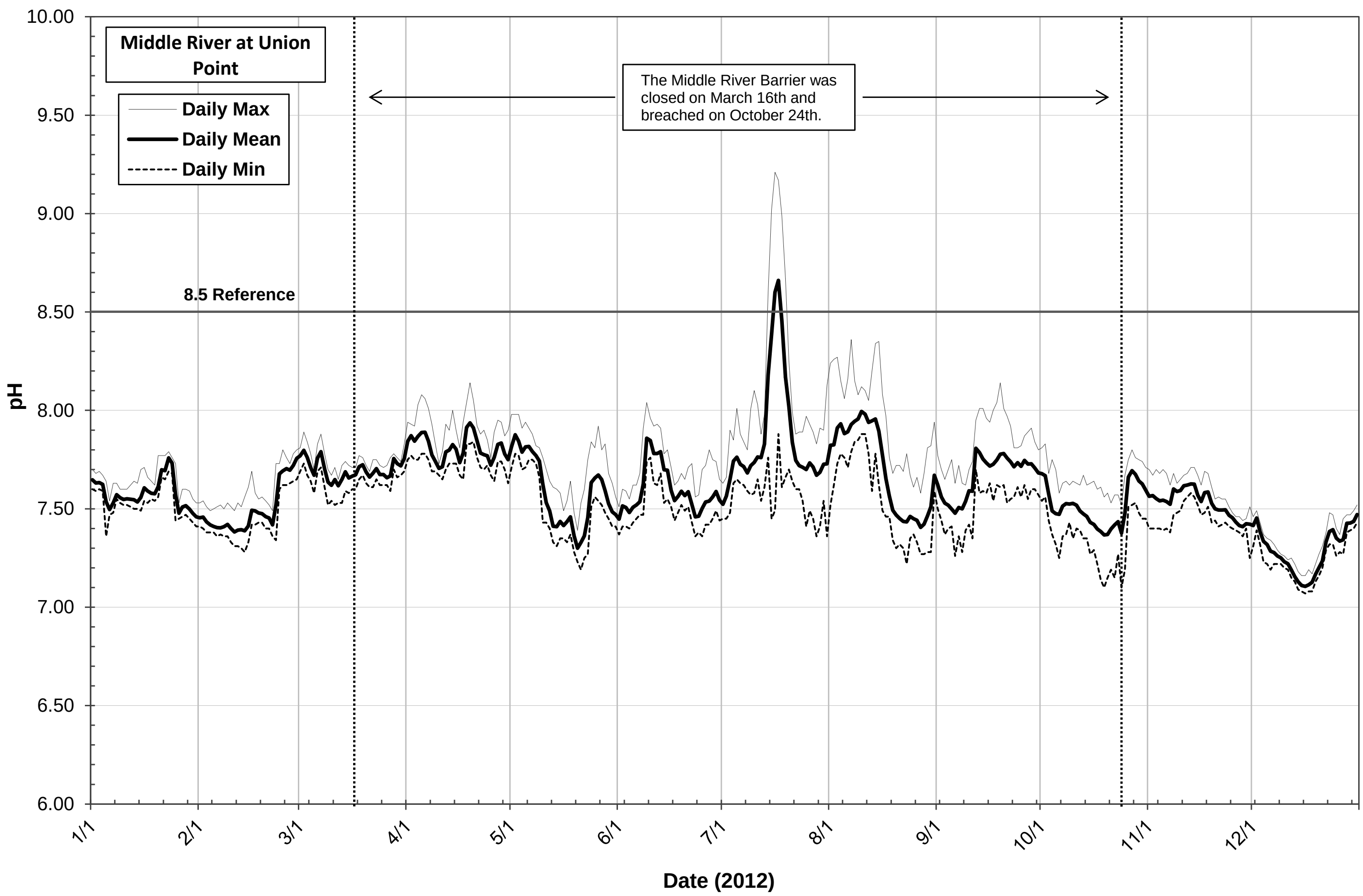
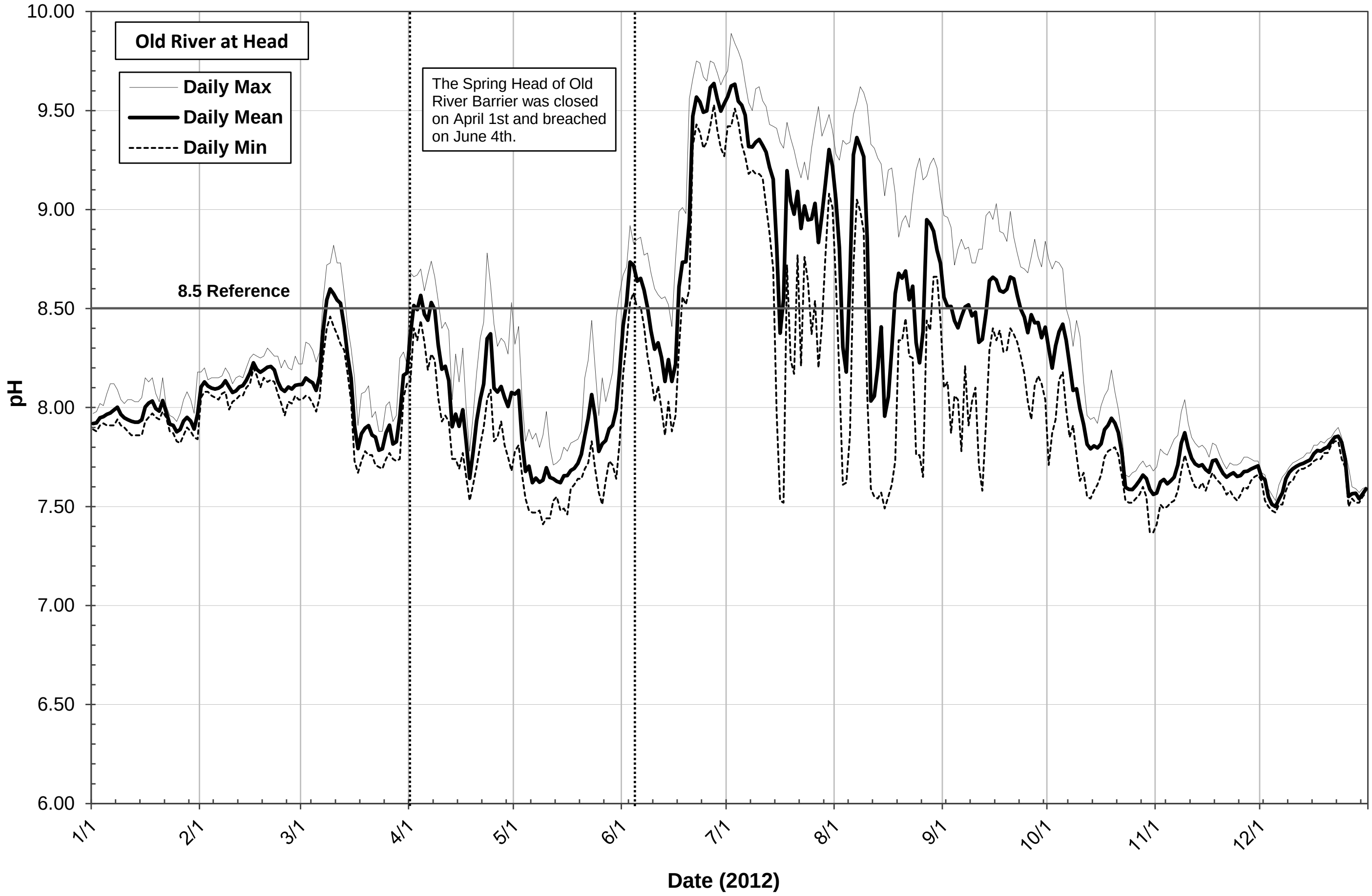


Figure 5-15: Daily pH time-series graphs for the Middle River stations



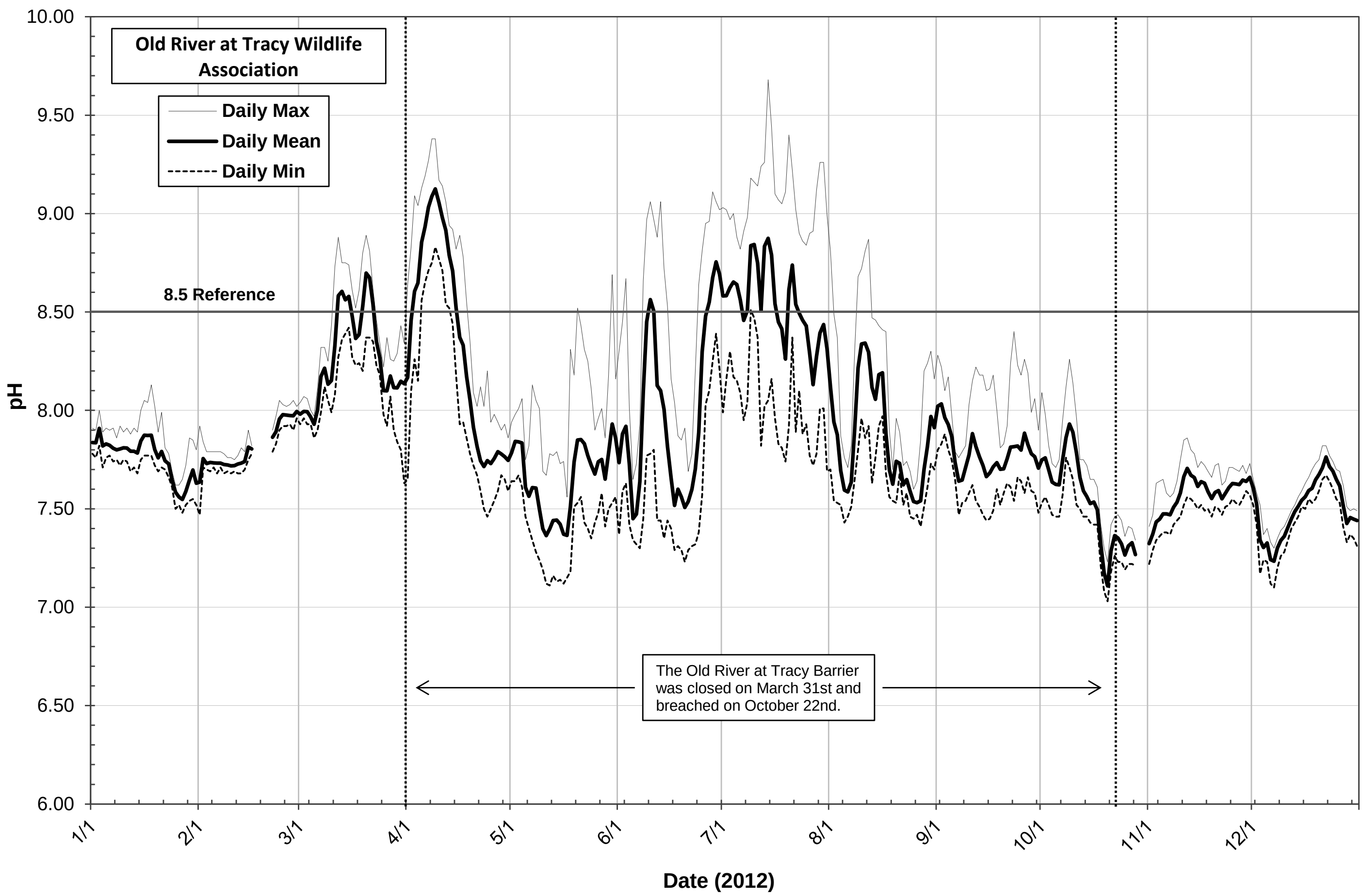
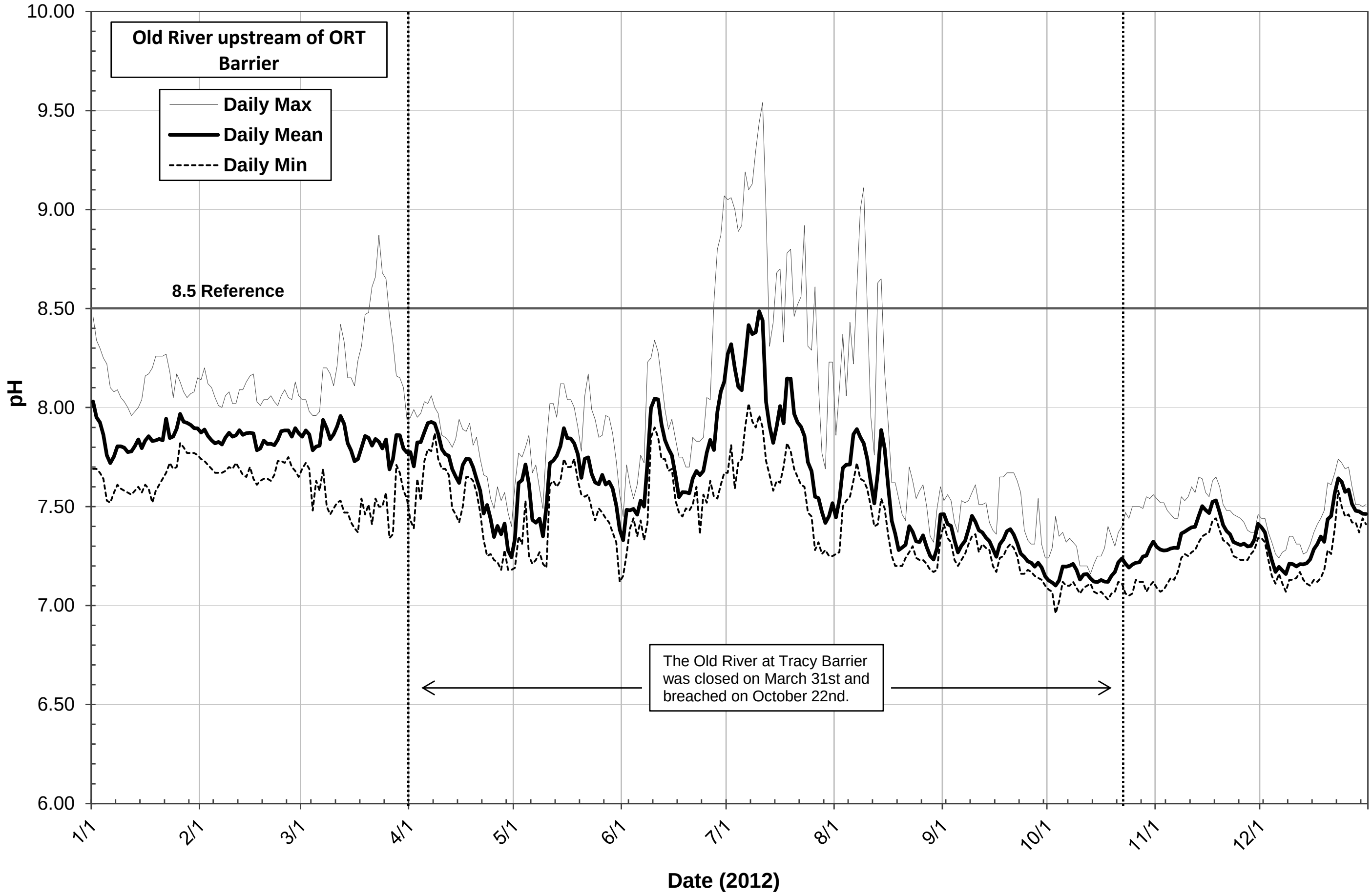


Figure 5-16: Daily pH time-series graphs for the Old River stations



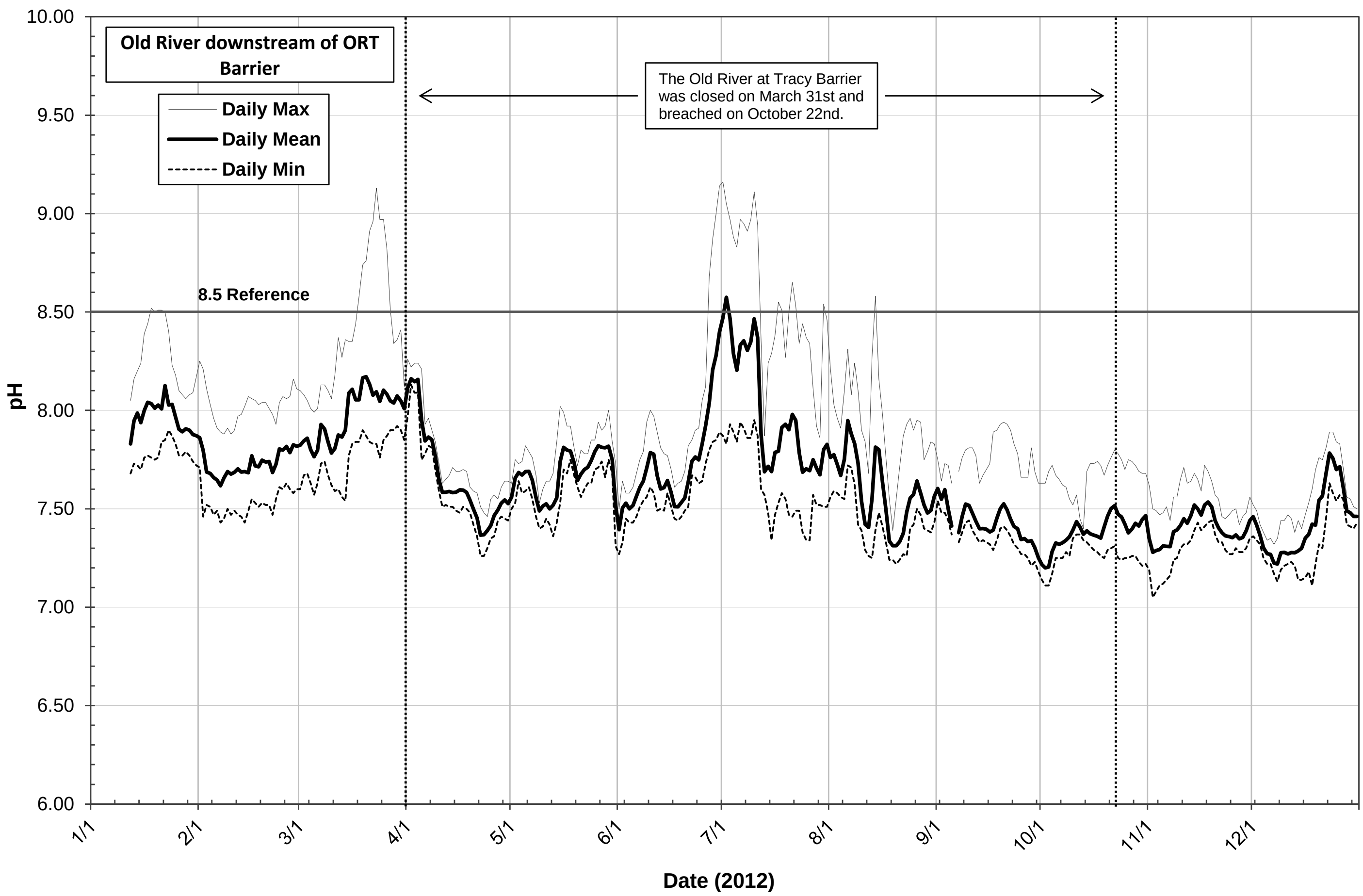
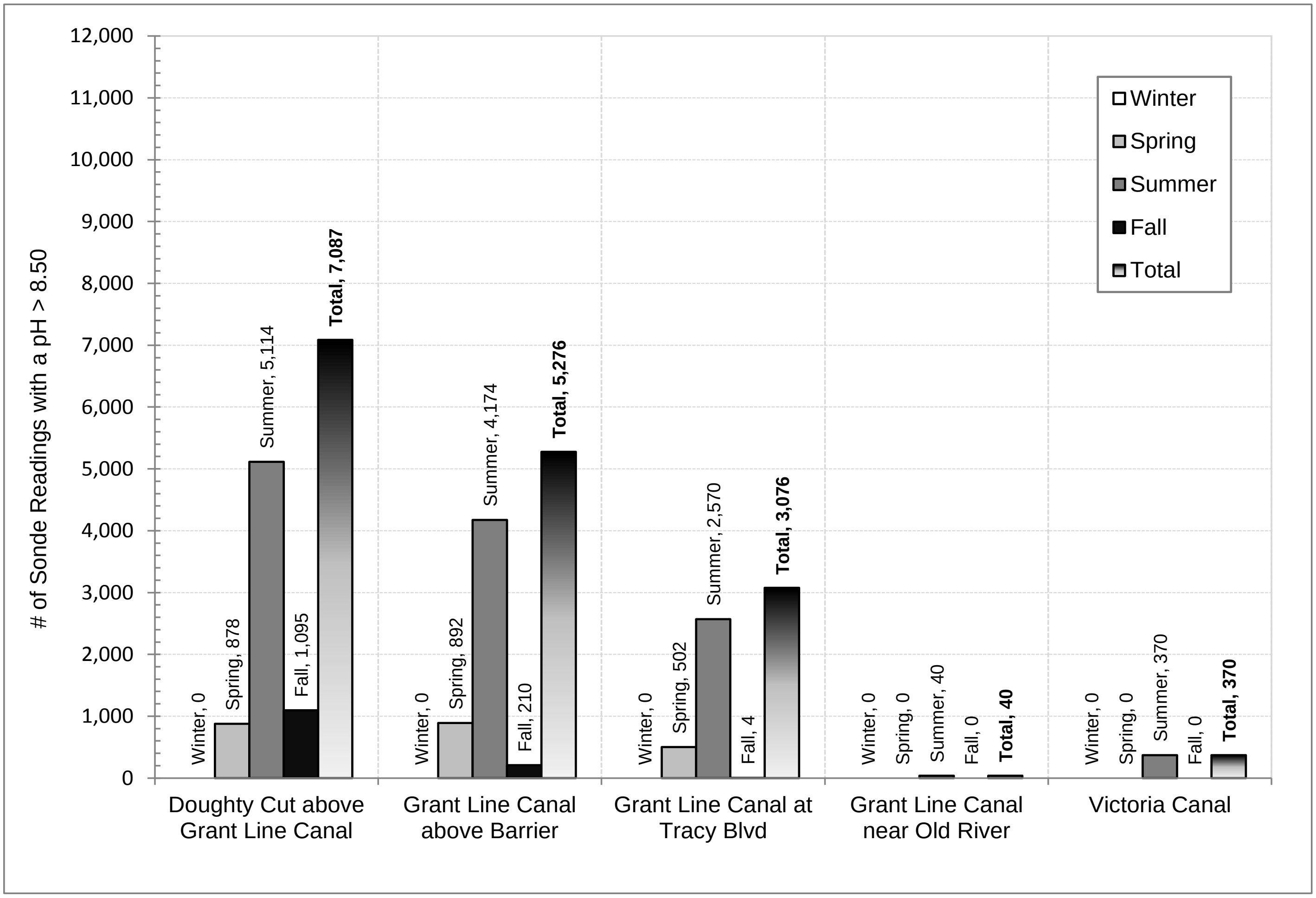


Figure 5-16: Daily pH time-series graphs for the Old River stations



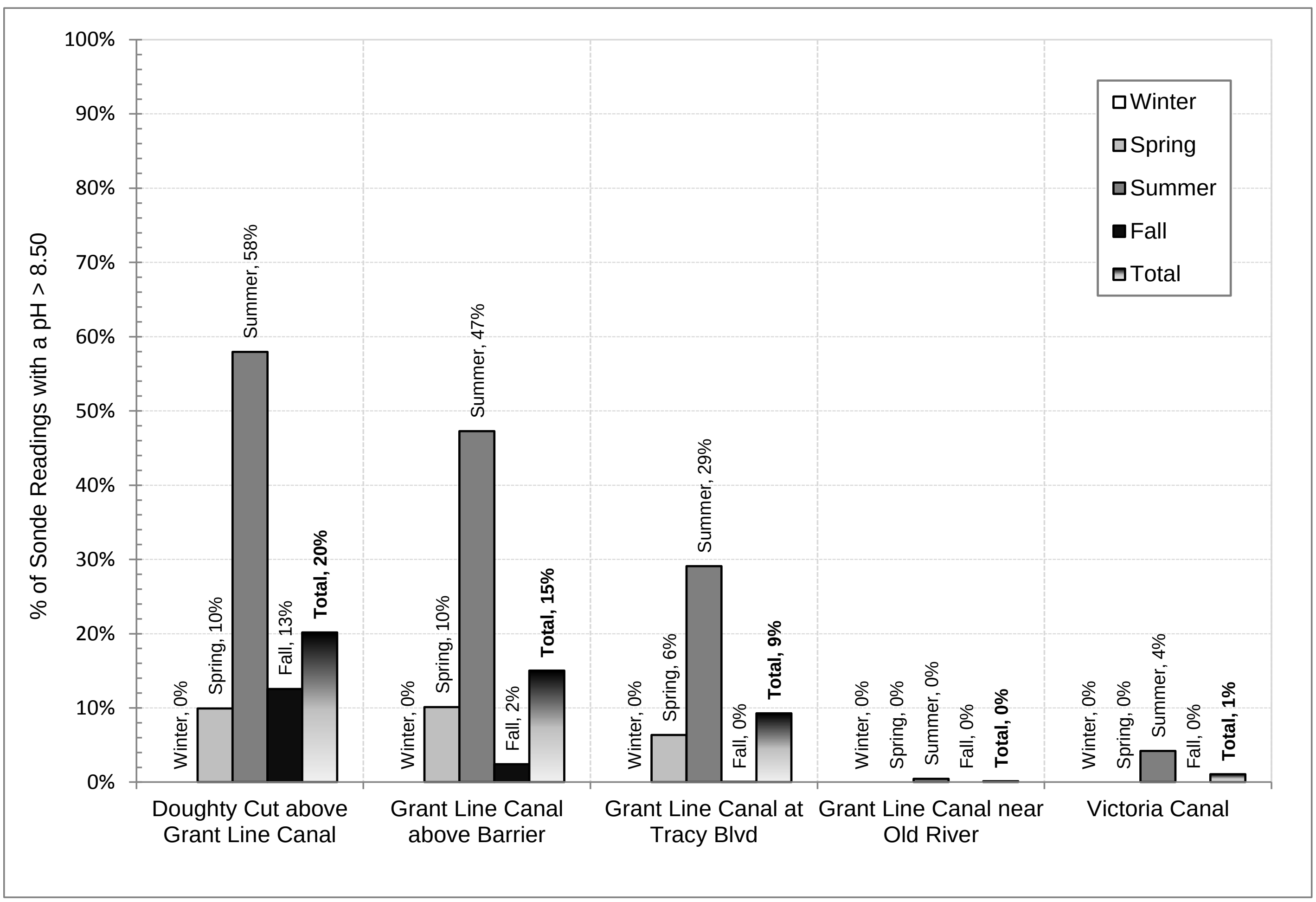
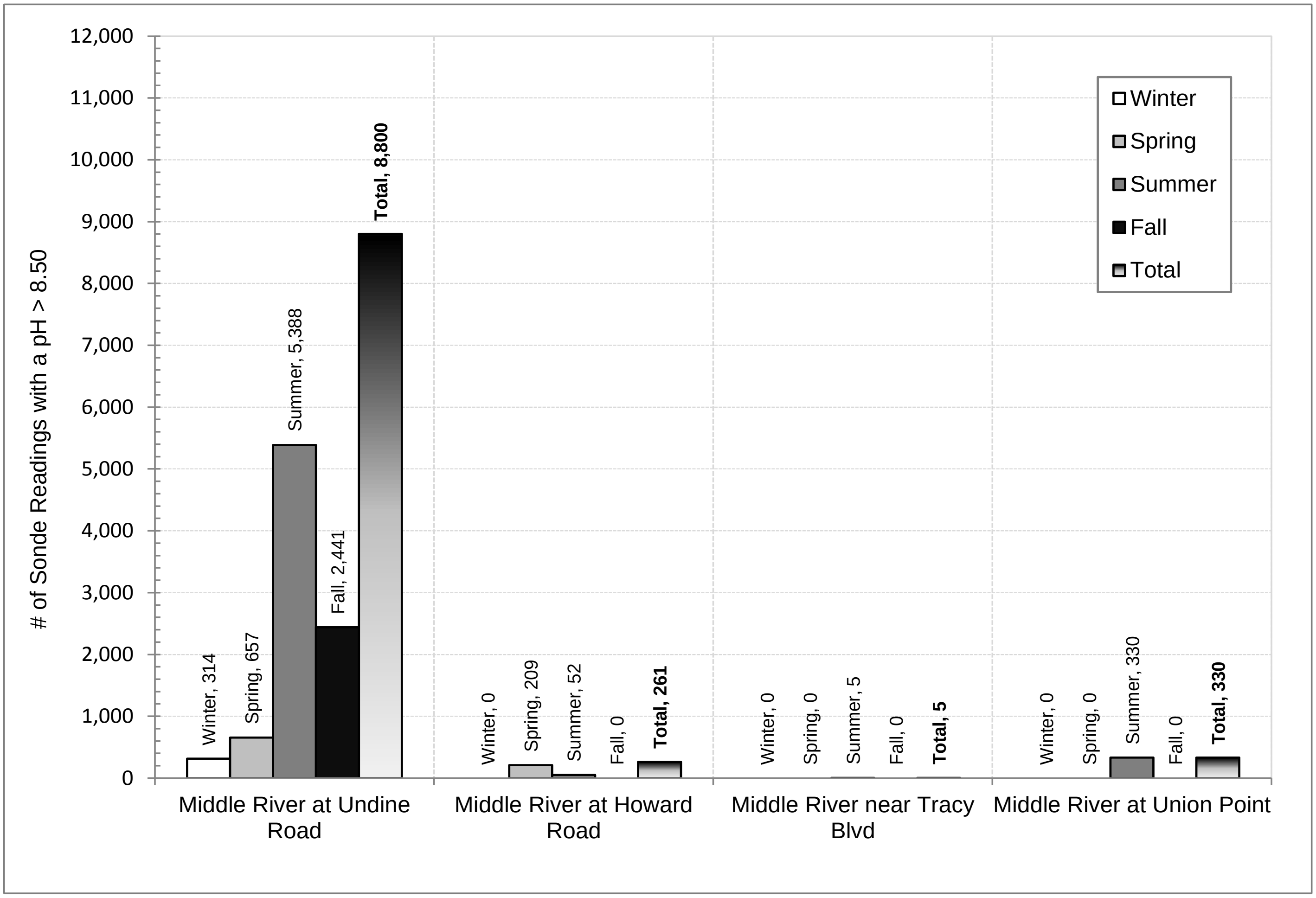


Figure 5-17: pH Standard Exceedences for the Grant Line and Victoria Canal stations



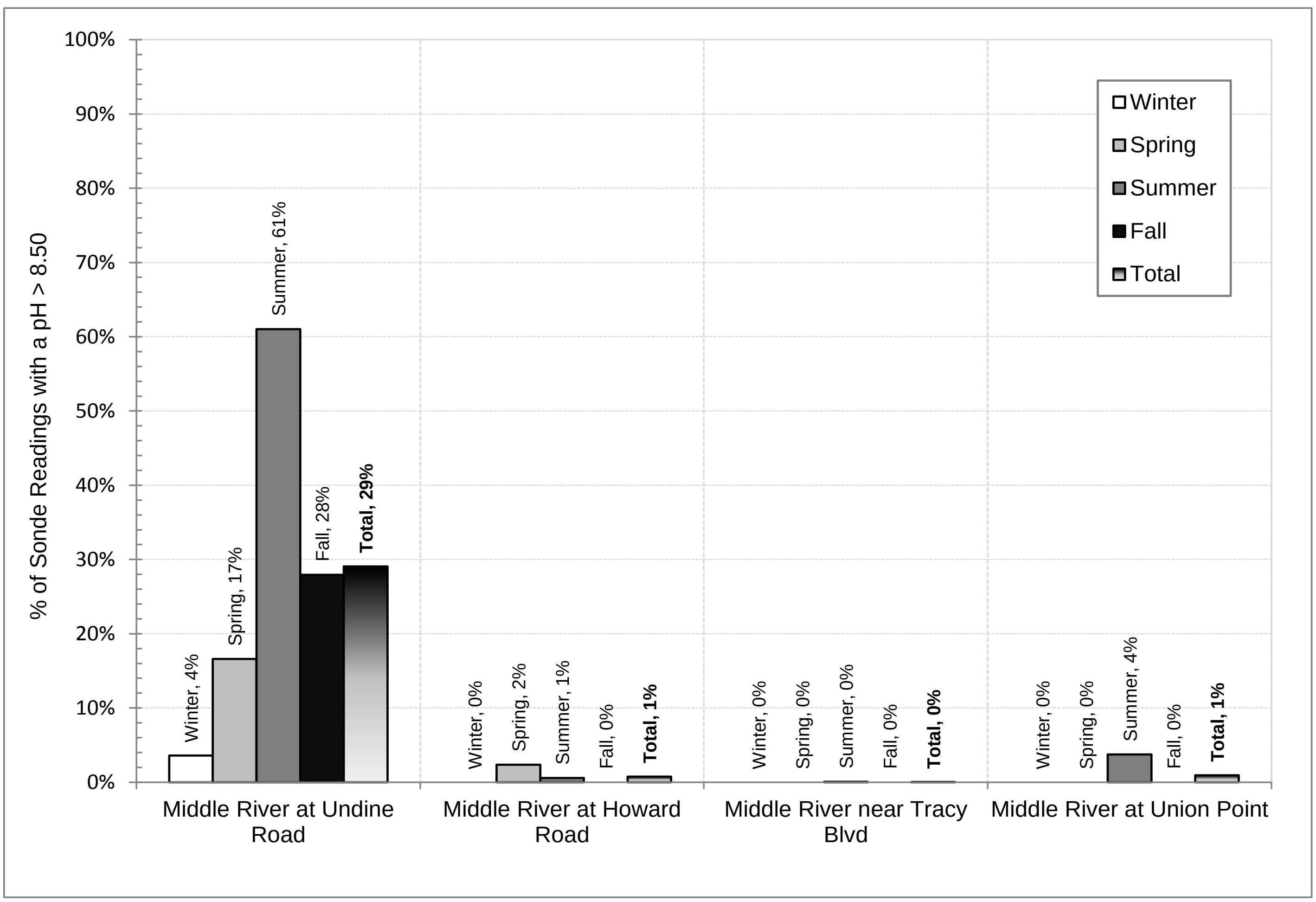
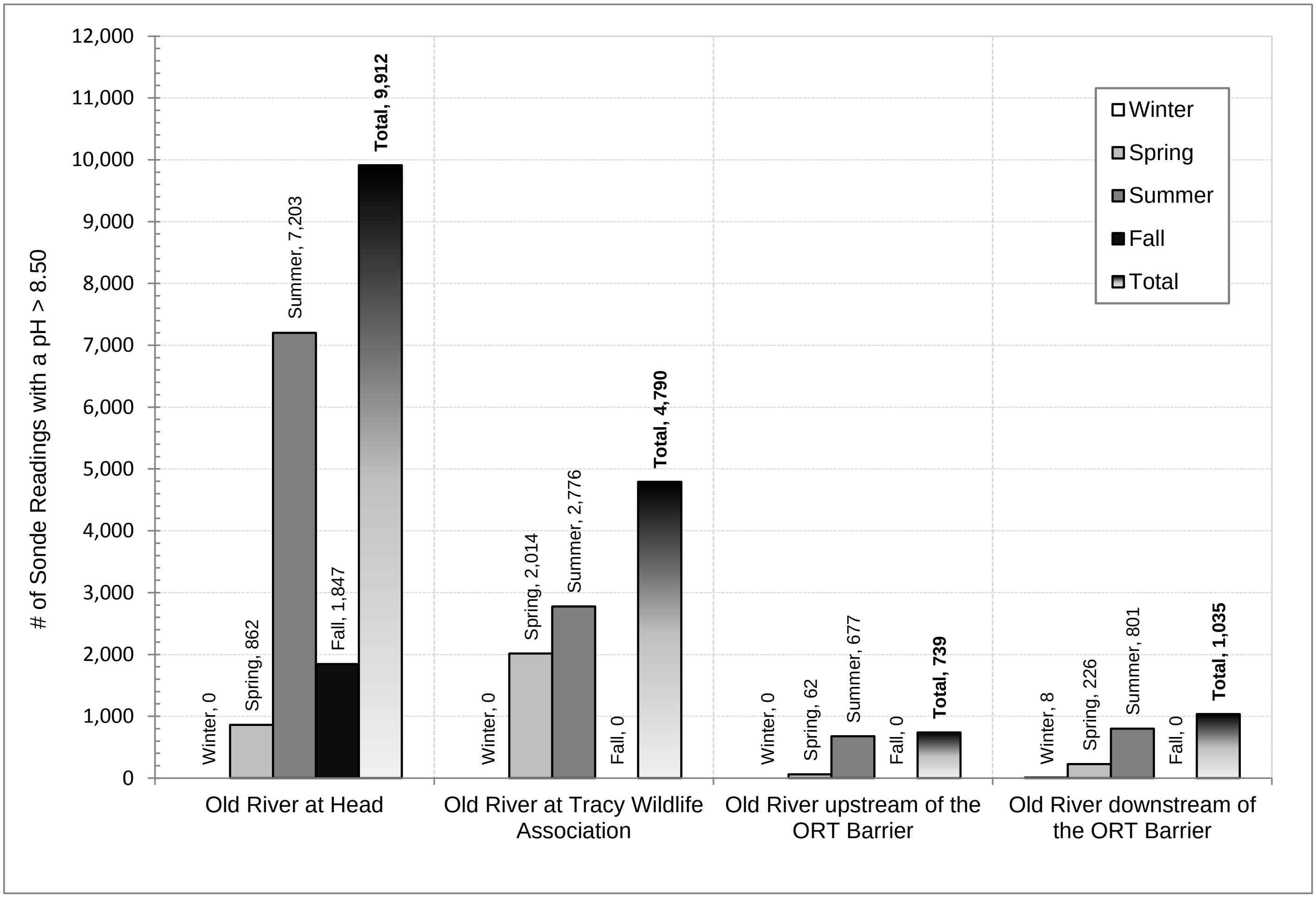


Figure 5-18: pH Standard Exceedences for the Middle River stations



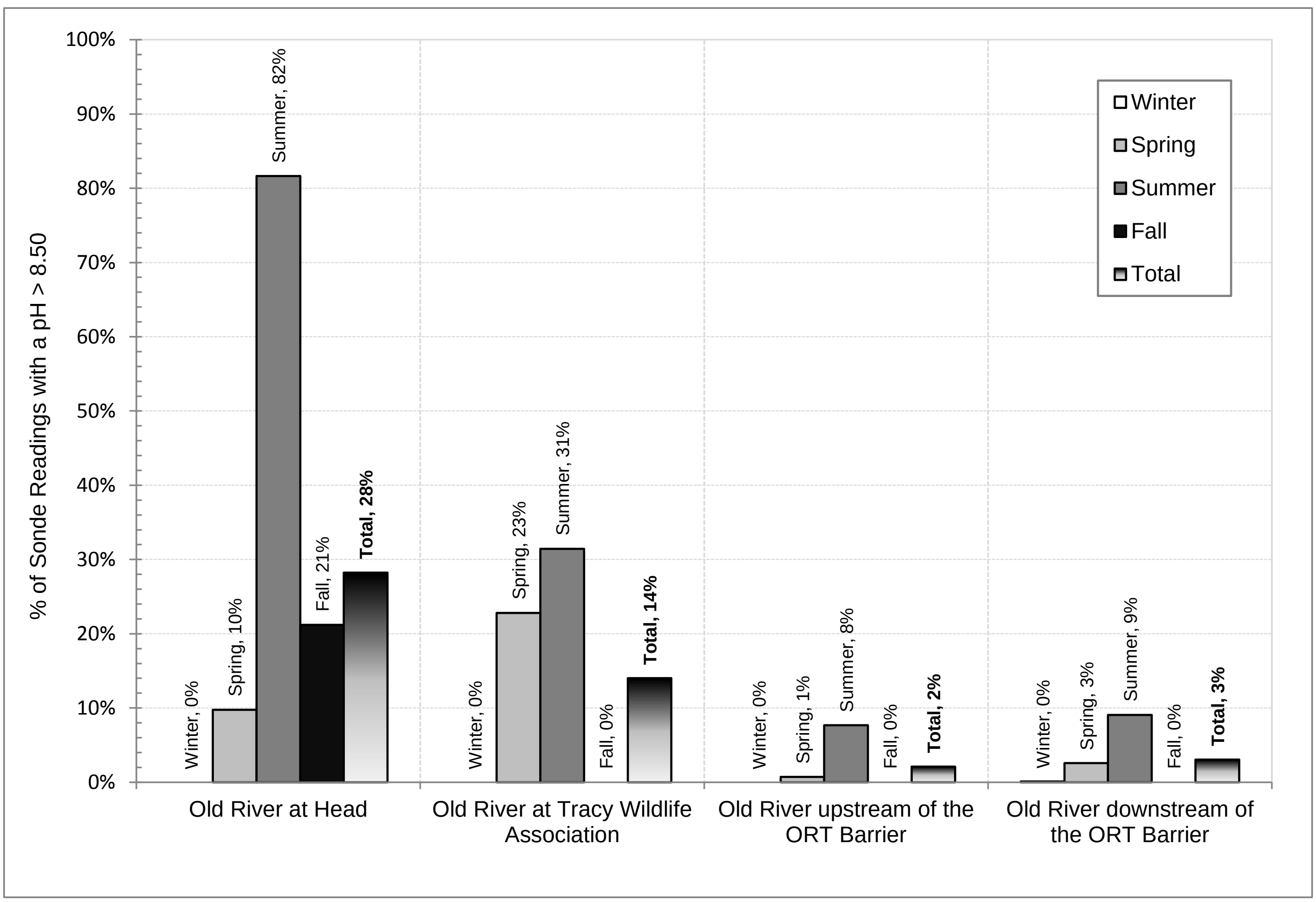


Figure 5-19: pH Standard Exceedences for the Old River stations

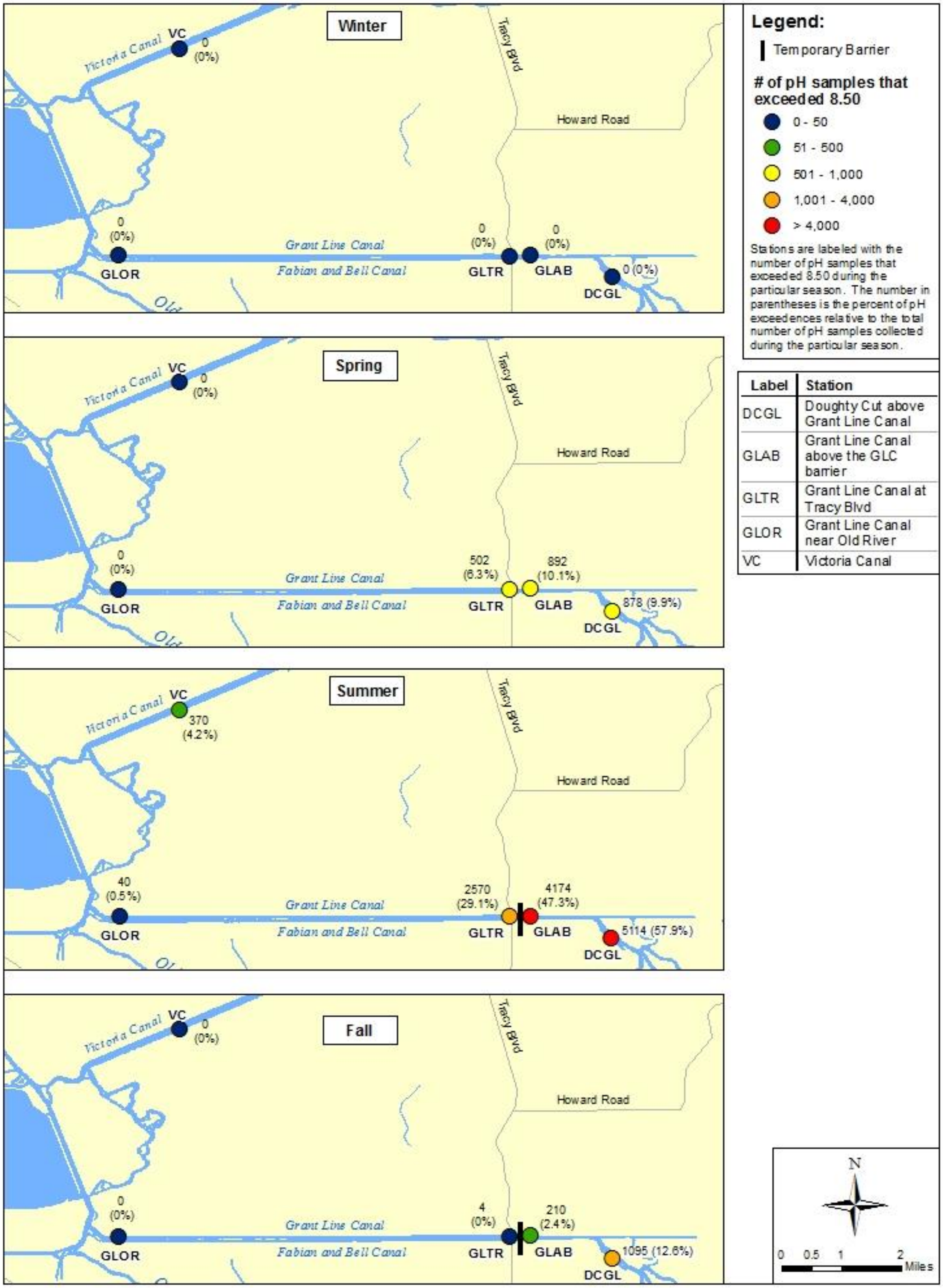


Figure 5-20: Map of pH Standard Exceedences for the Grant Line and Victoria Canal stations

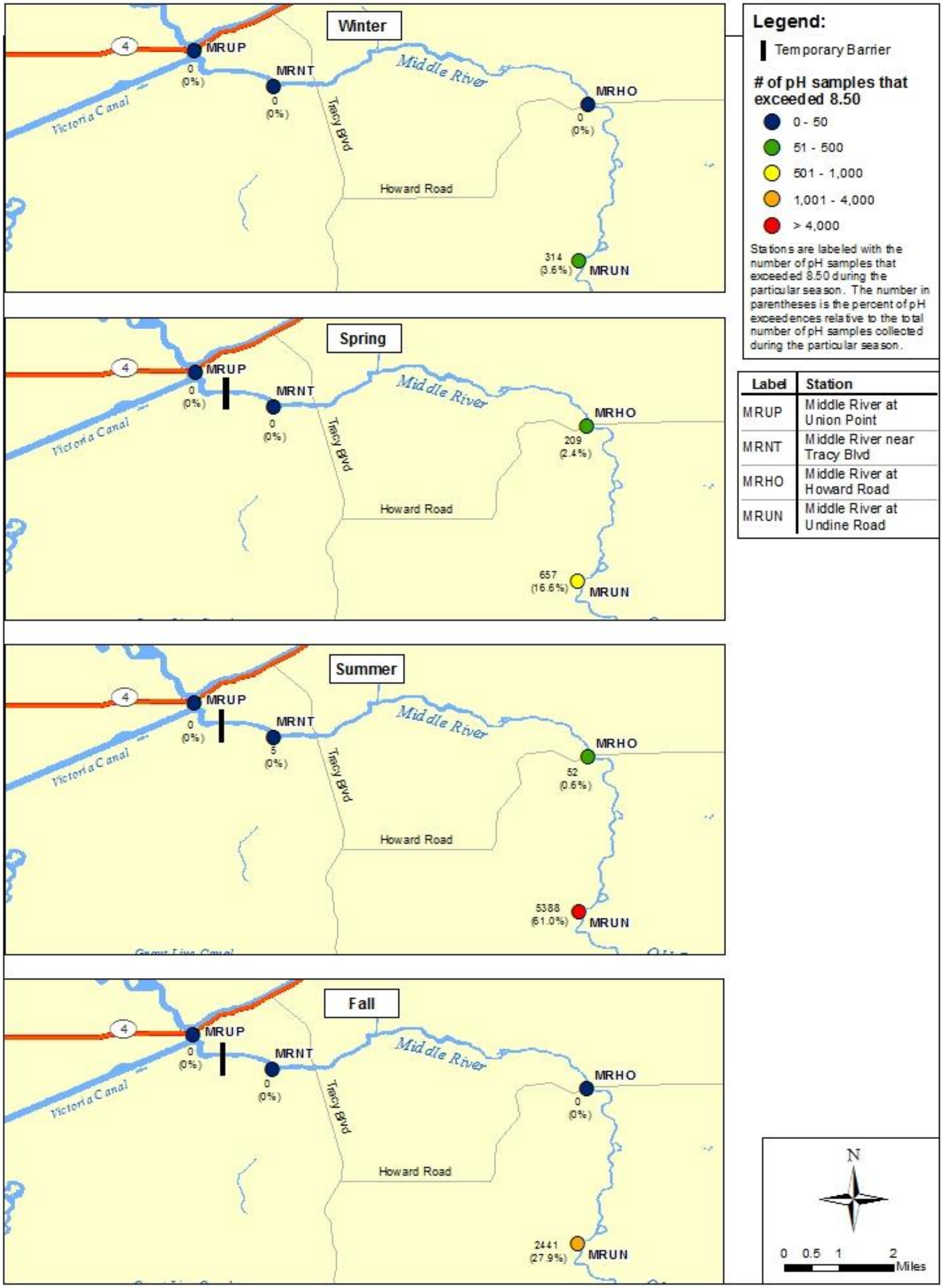


Figure 5-21: Map of pH Standard Exceedences for the Middle River stations

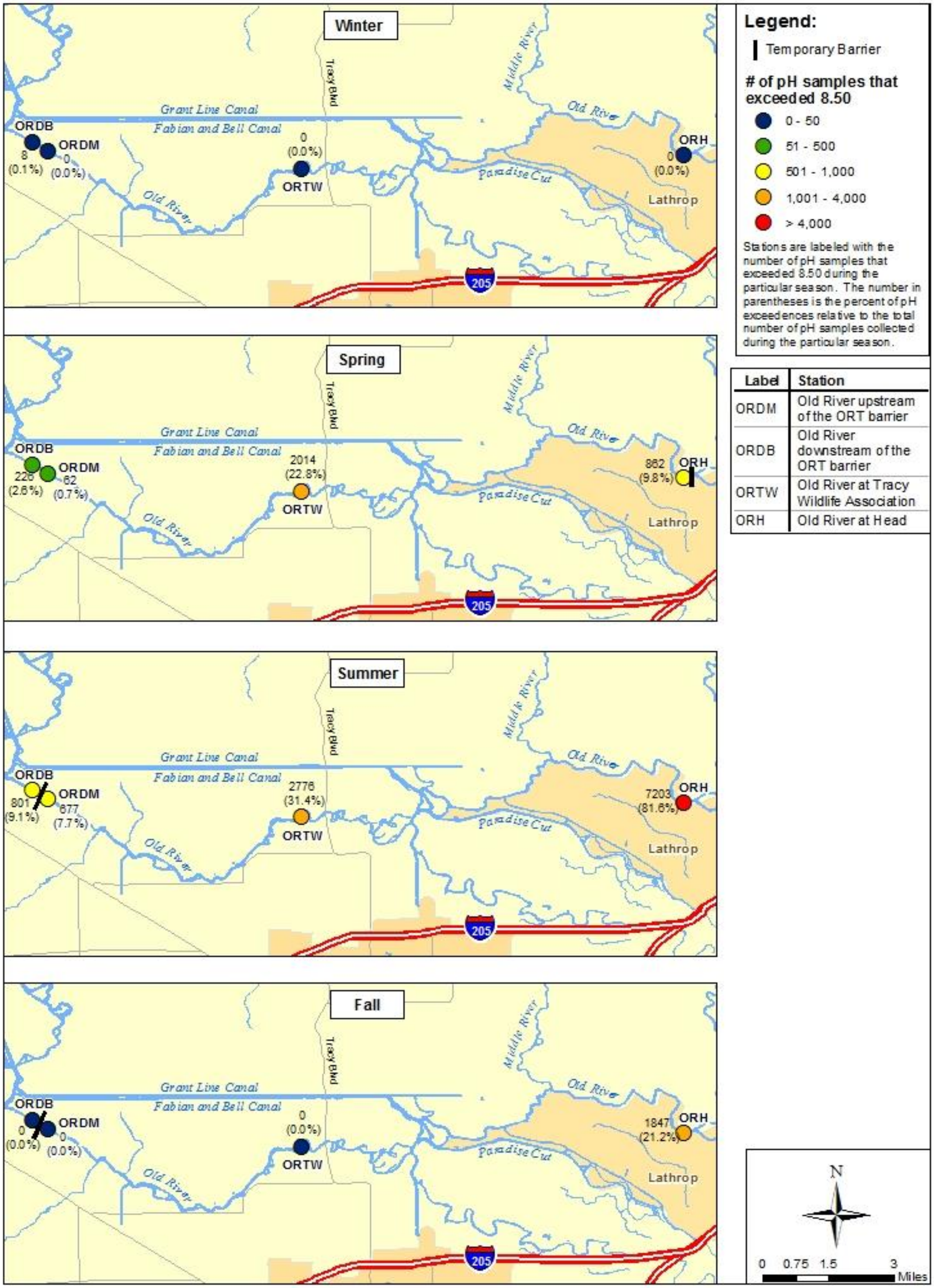


Figure 5-22: Map of pH Standard Exceedences for the Old River stations

Specific Conductance

Conductivity is a measure of the ability of an aqueous solution to carry an electrical current (APHA, 2005). Specific conductance values are temperature compensated to 25 ºC and can be used to estimate salinity and total dissolved solids (Wagner et al., 2006). Specific conductance is of vital importance in the South Delta because the water is used for irrigation. High amounts of dissolved salts in irrigation water can result in crop damage and reduced yield. Specific conductance data measured at various locations along a particular waterbody can be used to determine if a major input of water with a different conductivity enters the system between the locations; a significant difference at one or more locations could indicate that the water nearby these sites comes from a different source composition.

Tables 5-3, 5-4, 5-5, and 5-6 provide monthly summary statistics for the Grant Line Canal, Victoria Canal, Middle River, and Old River stations, respectively. In addition, Figures 5-23, 5-24, and 5-25 illustrate the daily maximums, minimums, and averages for the Grant Line and Victoria Canal, Middle River, and Old River stations, respectively. Most stations had higher specific conductance during the end of February and March due to a dry winter. Specific conductance values decreased during April and May due to spring and early summer snowmelt, and higher flows in the lower San Joaquin River due to the Vernalis Adaptive Management Plan[7]. During summer, specific conductance values increased at most South Delta stations, yet monthly average values remained under 700 µS/cm. There were two periods, late fall and winter, where noticeable decreases in specific conductance values were observed. Specific conductance values decreased during October and November due to early rain events, and higher flows in the lower San Joaquin River due to the Vernalis Adaptive Management Plan.

The State Water Resources Control Board has specific conductivity objectives for three sites in the South Delta; San Joaquin River at Brandt Bridge, Old River near Middle River, and Old River at Tracy Road Bridge. The thirty-day running average for these sites should not exceed 700 µS/cm from April 1st-August 31st and 1,000 µS/cm from September 1st-March 31st.

April through August 2012 – Agricultural Season

The maximum recorded specific conductance during this time period was 1,723 µS/cm on May 21st at Middle River at Howard Road, and the minimum was 187 µS/cm on May 12th at Old River at Head (Tables 5-3 to 5-6). Monthly mean values for this time period ranged from 240 µS/cm in August at Middle River at Union Point to 1,302 µS/cm in April at Old River at Tracy Wildlife Association.

January-March 2012 and September-December 2012

The maximum recorded specific conductance during this time period was 1,594 µS/cm on March 8th at Old River below the ORT Barrier, and the minimum was 258 µS/cm on October 23rd at Old River at Head (Tables 5-3 to 5-6). Monthly mean values for this time period ranged from 337 µS/cm at Victoria Canal and Middle River at Union Point to 1,129 µS/cm at Old River at Tracy Wildlife Association.

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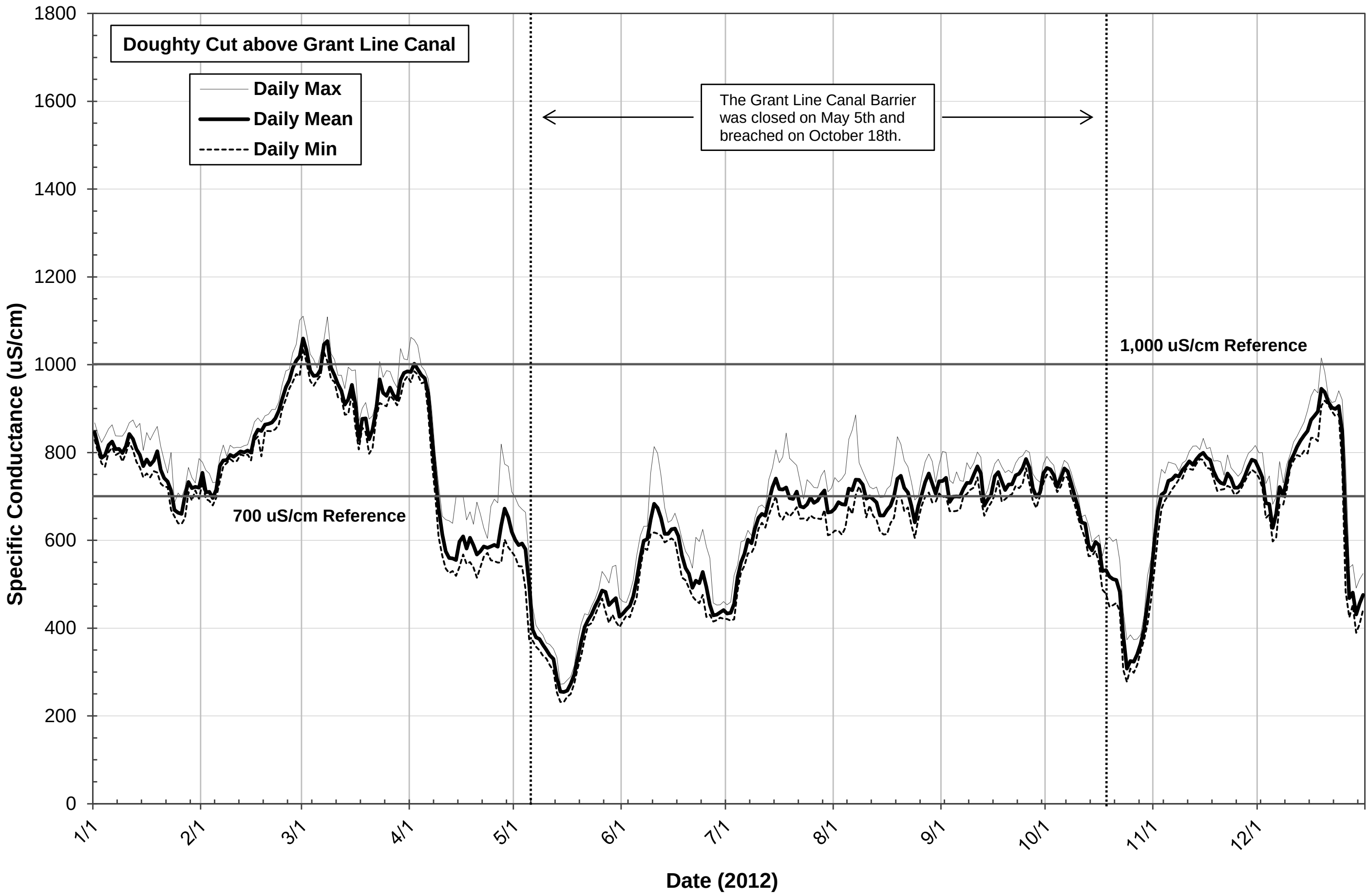
[7] The Vernalis Adaptive Management Plan is a long-term program designed to protect migrating juvenile Chinook salmon in the South Delta. The plan includes increasing the flow in the lower San Joaquin River from April through May by releasing more water from upstream reservoirs.



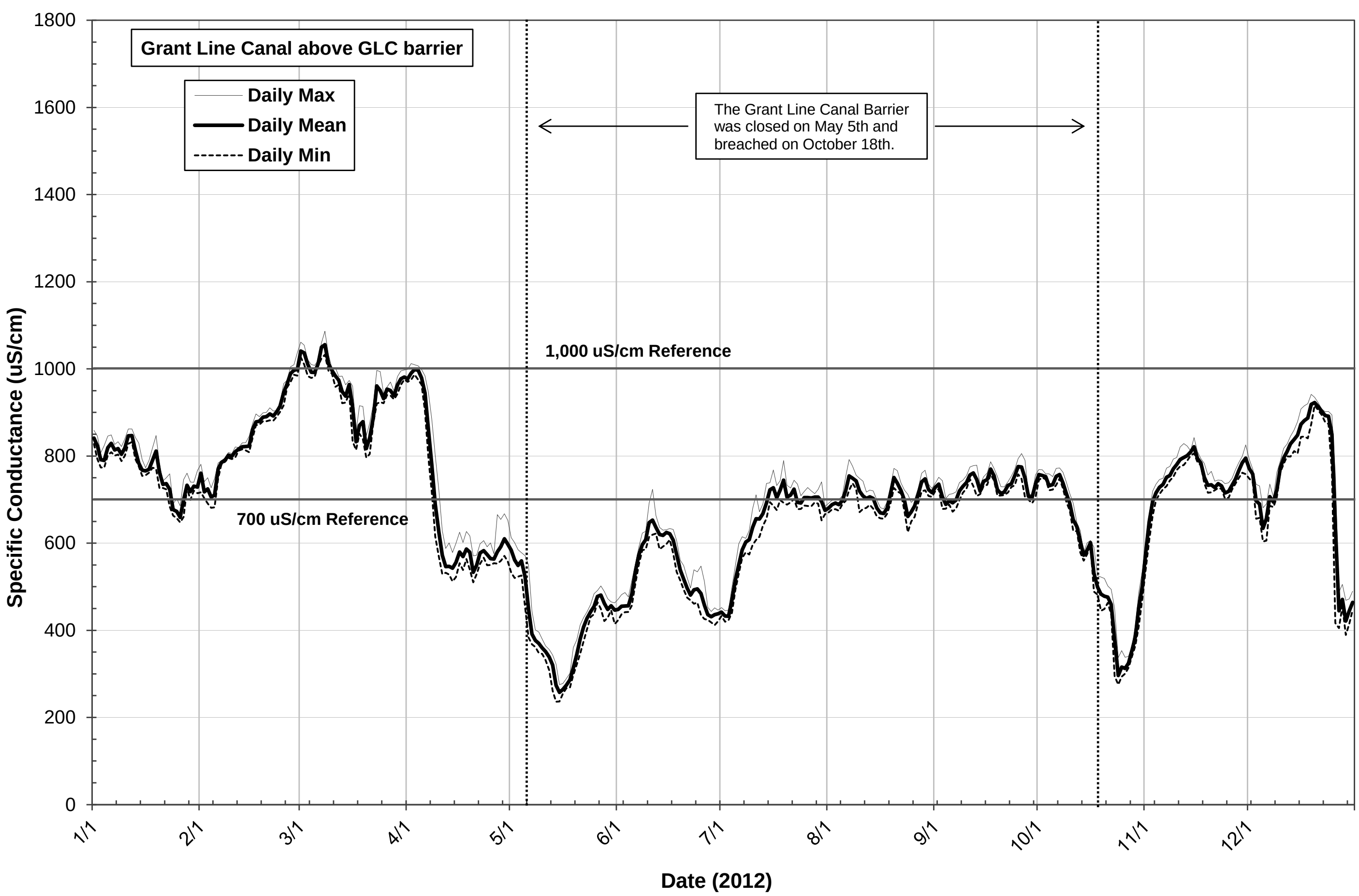
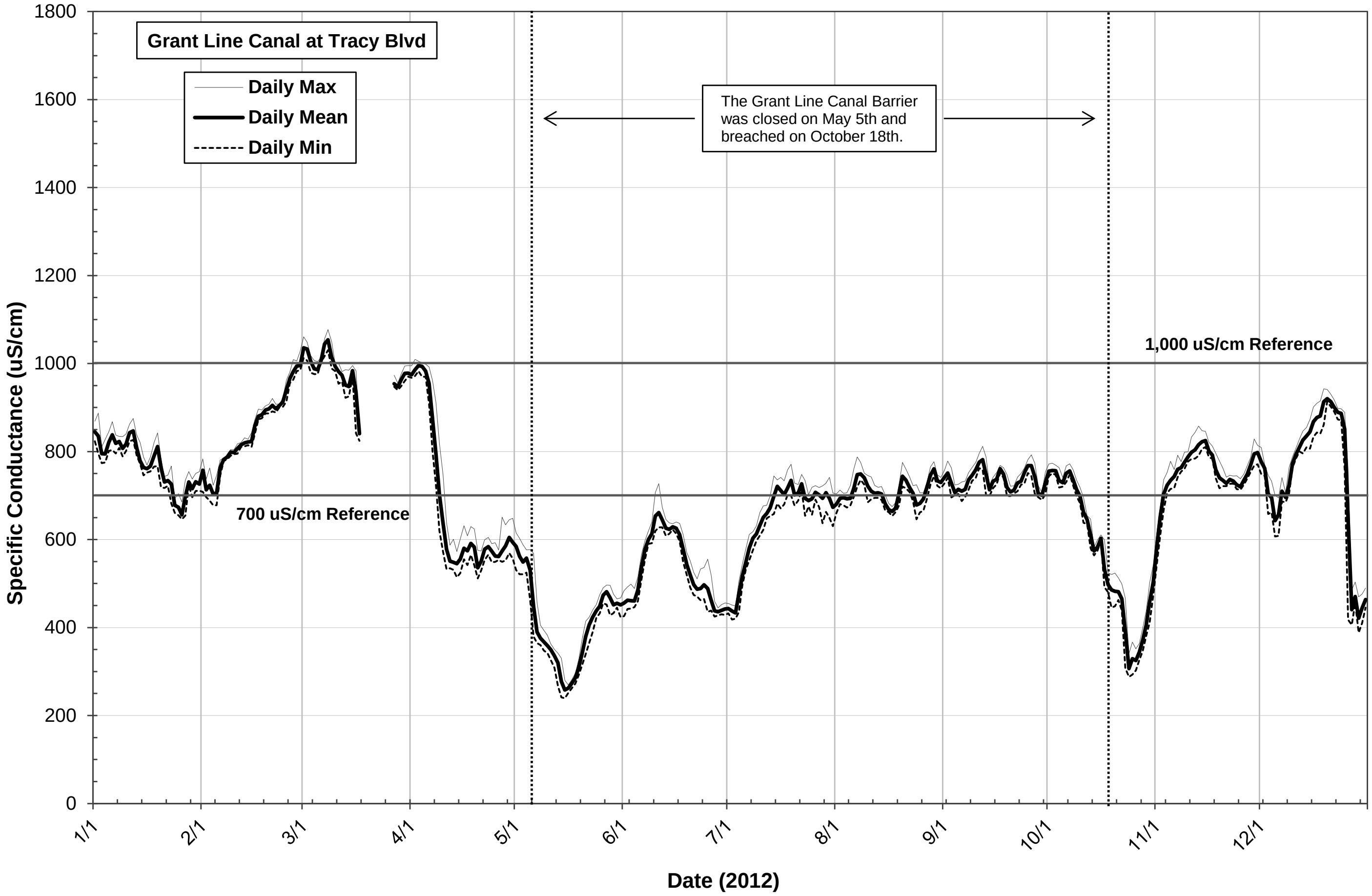


Figure 5-23: Daily Specific Conductance time-series graphs for the Grant Line and Victoria Canal stations



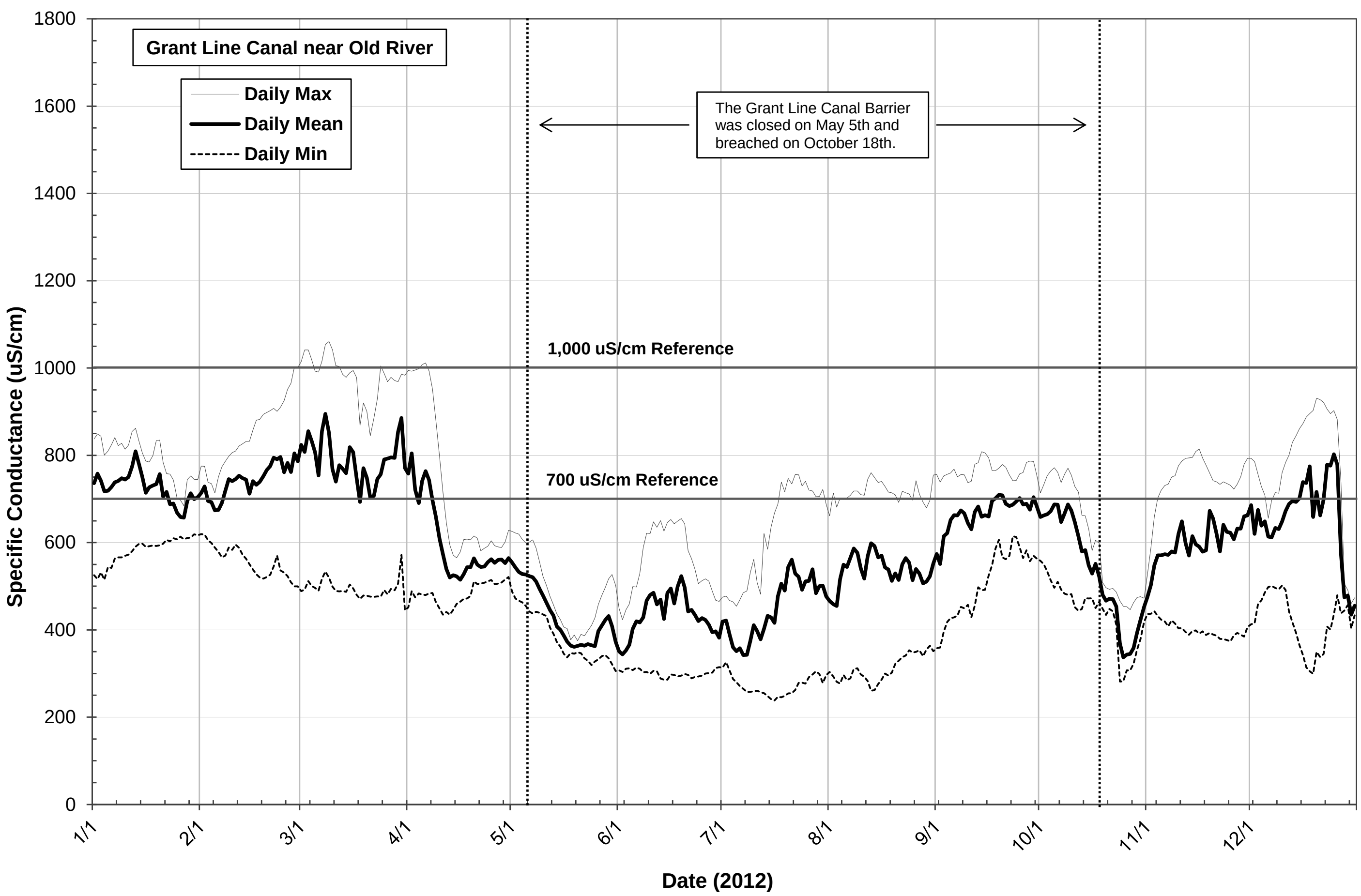


Figure 5-23: Daily Specific Conductance time-series graphs for the Grant Line and Victoria Canal stations

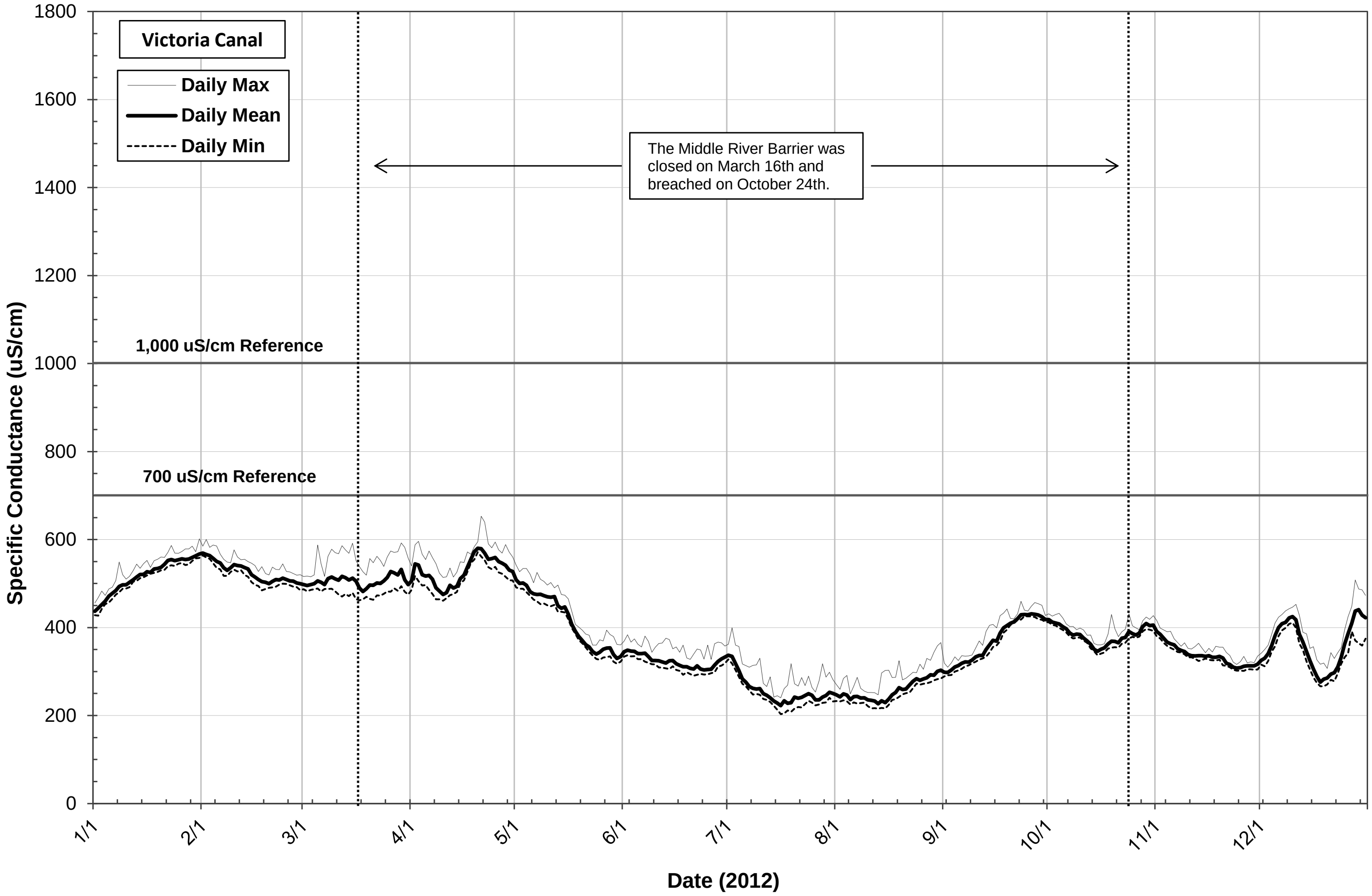
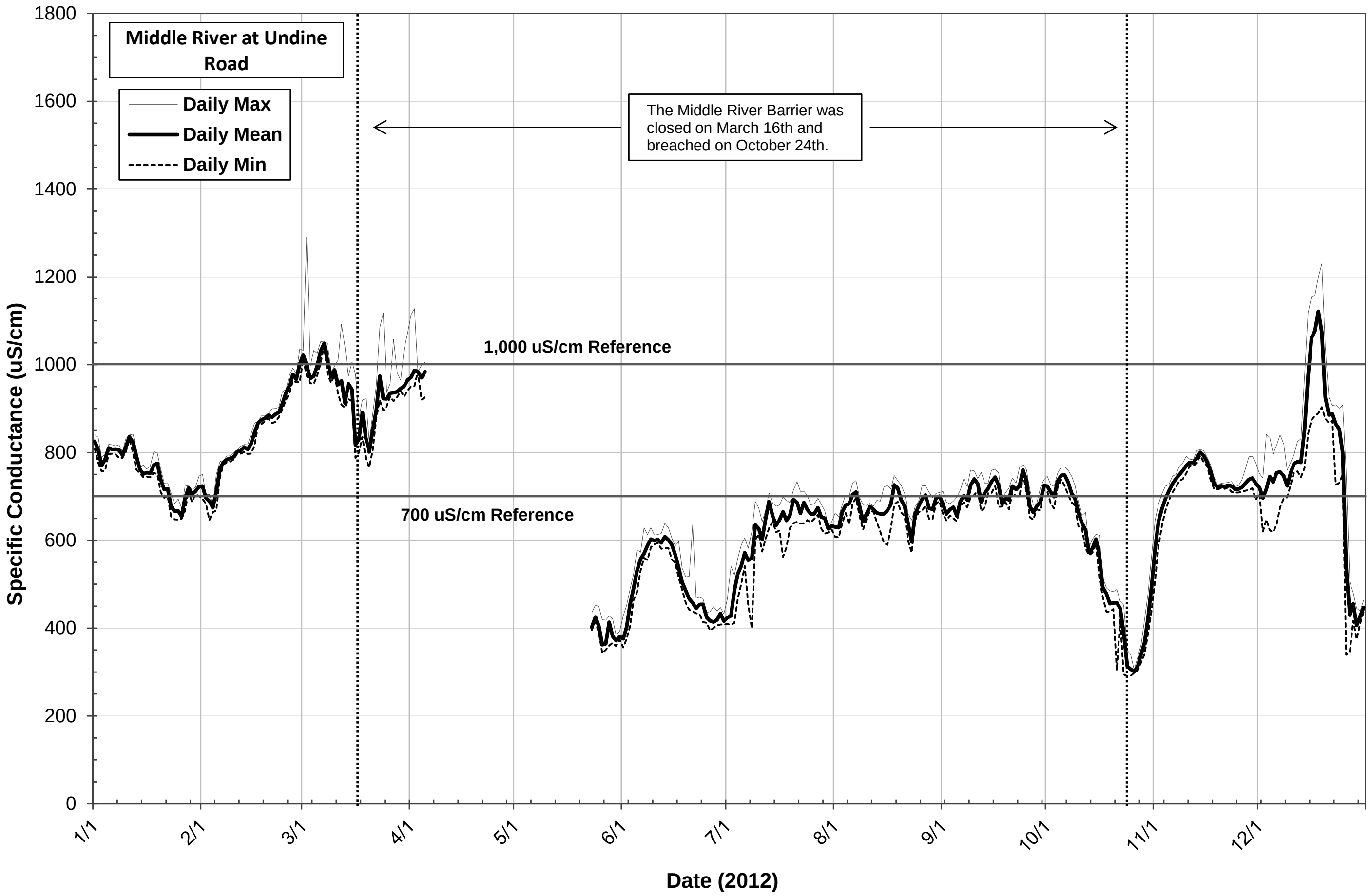


Figure 5-23: Daily Specific Conductance time-series graphs for the Grant Line and Victoria Canal stations



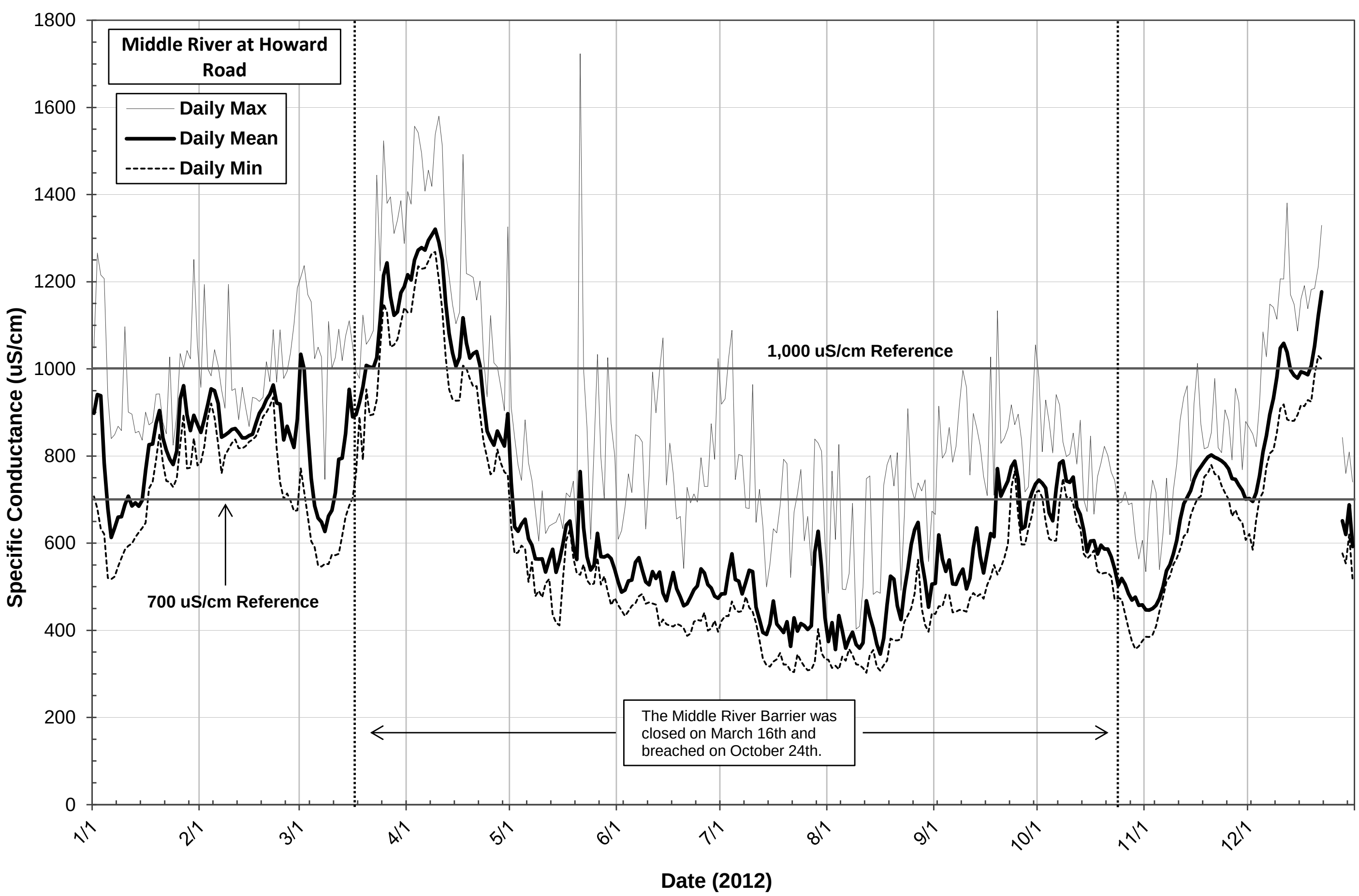
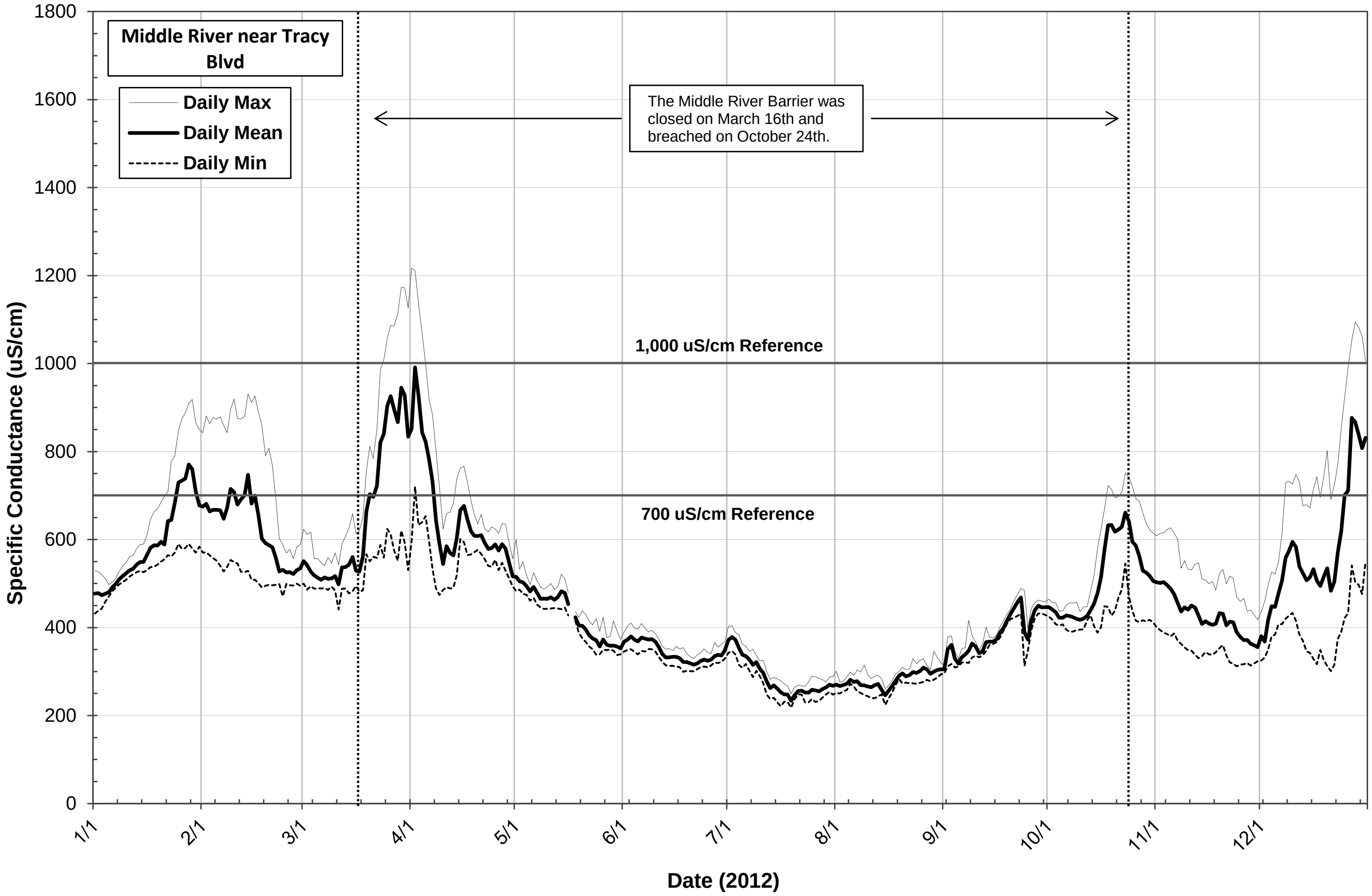


Figure 5-24: Daily Specific Conductance time-series graphs for the Middle River stations



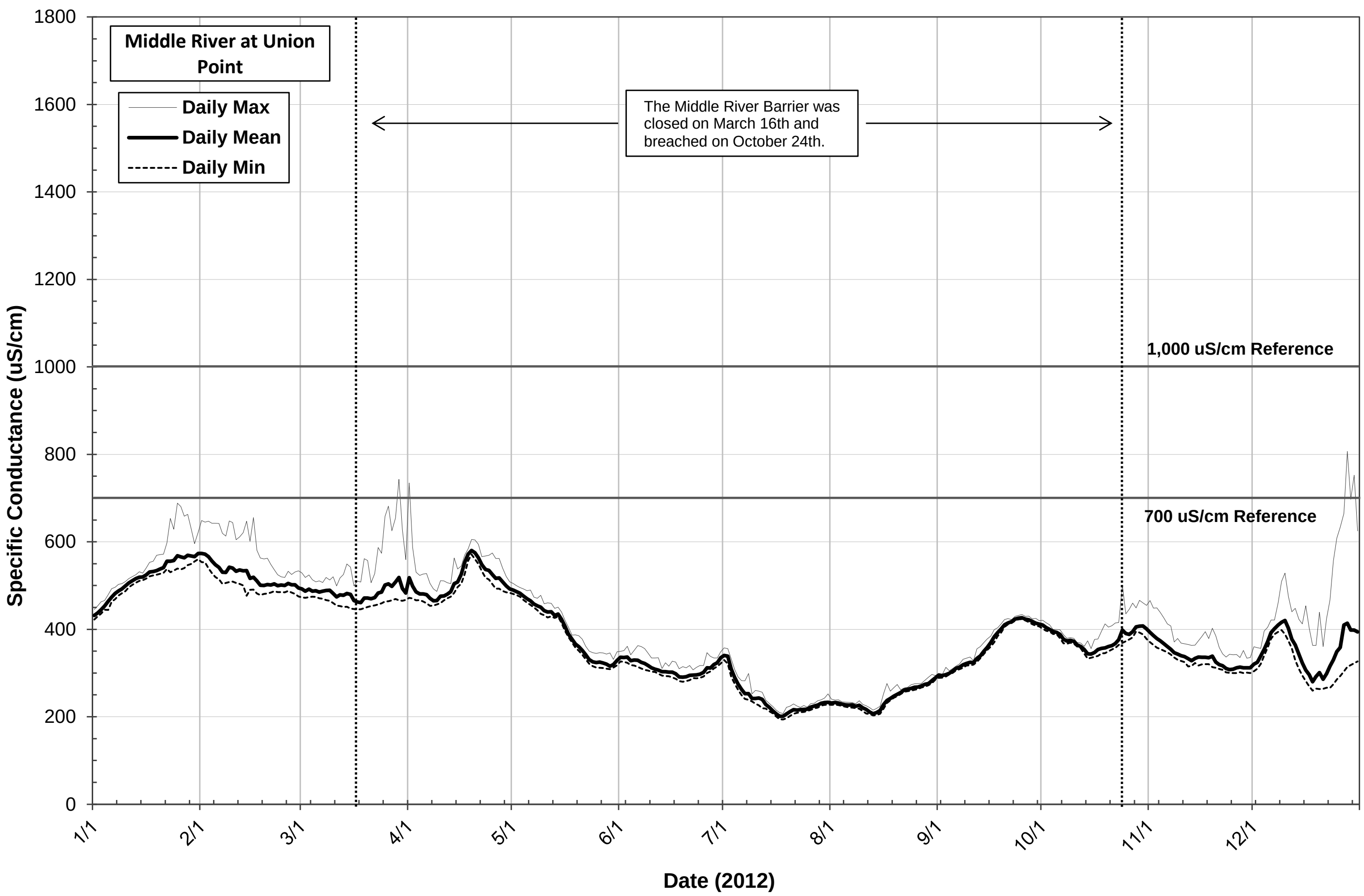
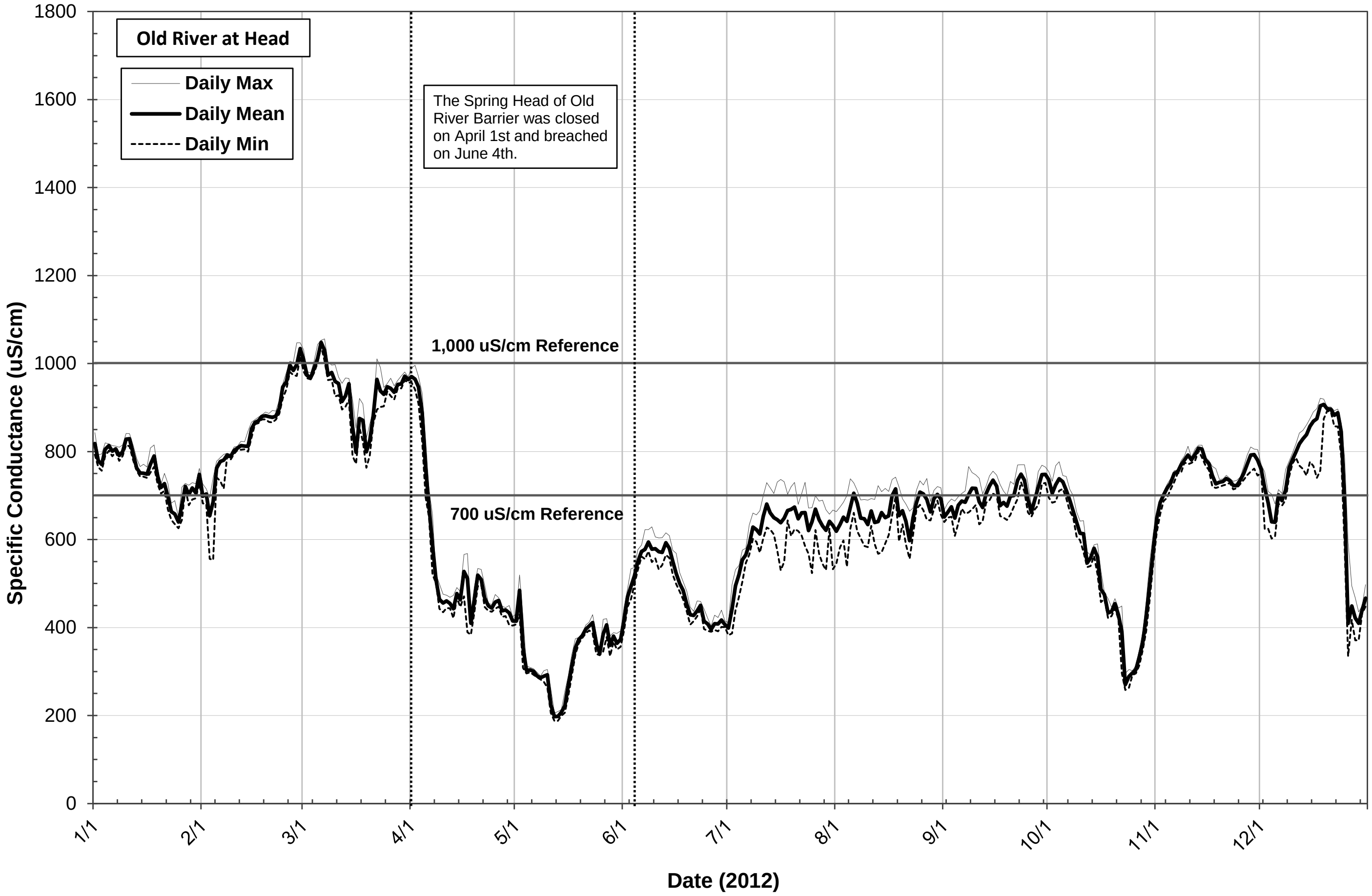


Figure 5-24: Daily Specific Conductance time-series graphs for the Middle River stations



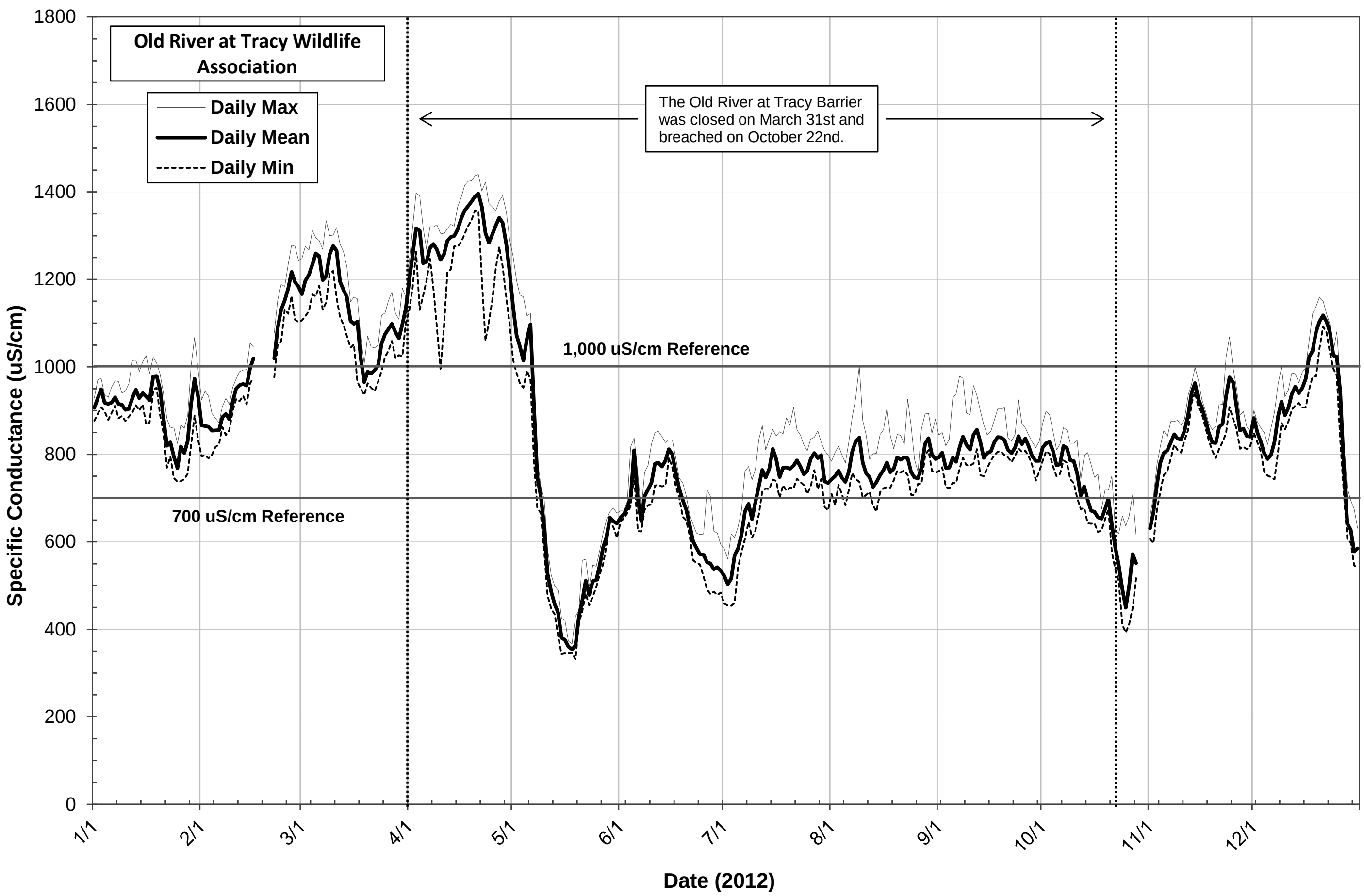
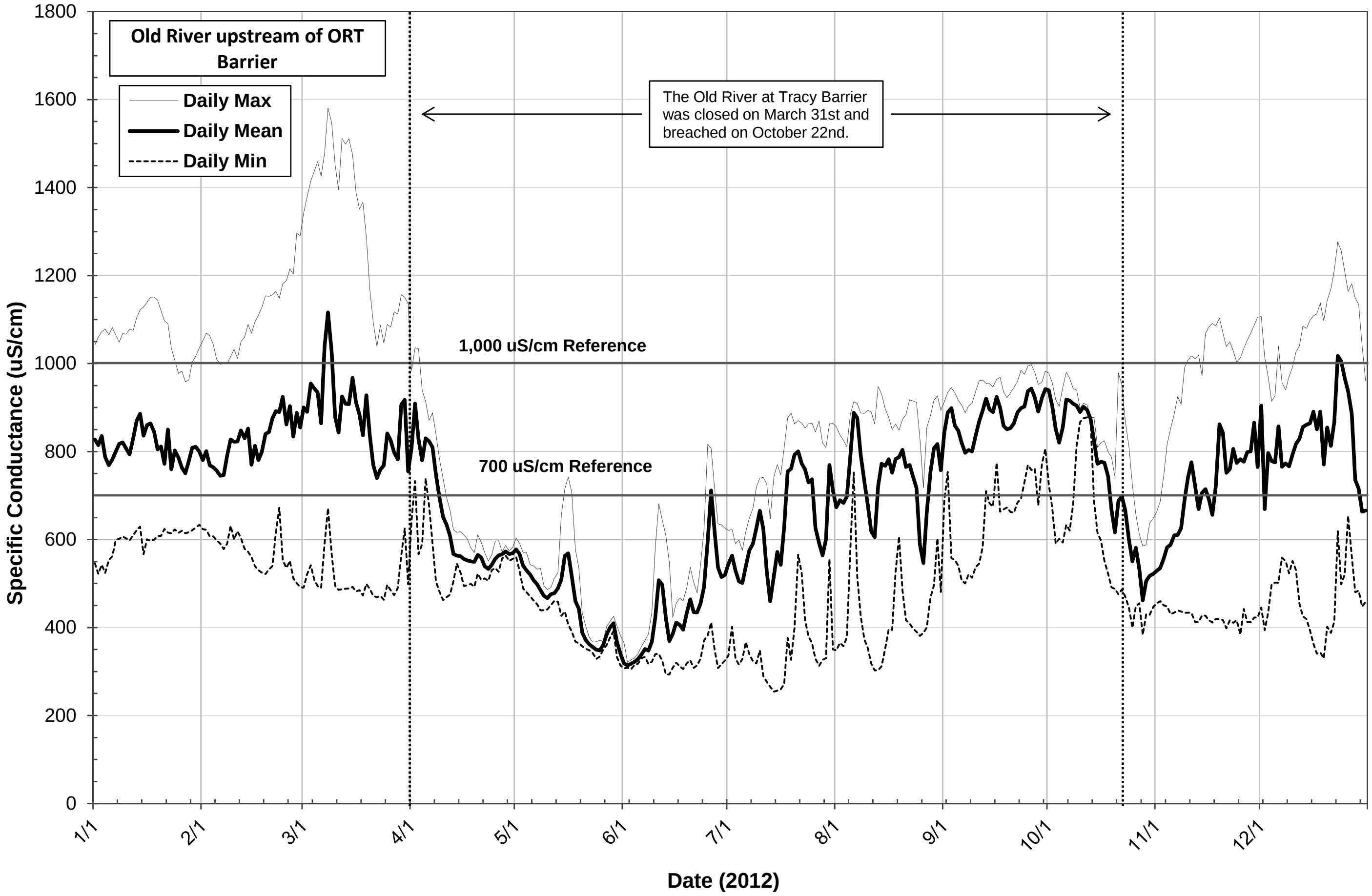


Figure 5-25: Daily Specific Conductance time-series graphs for the Old River stations



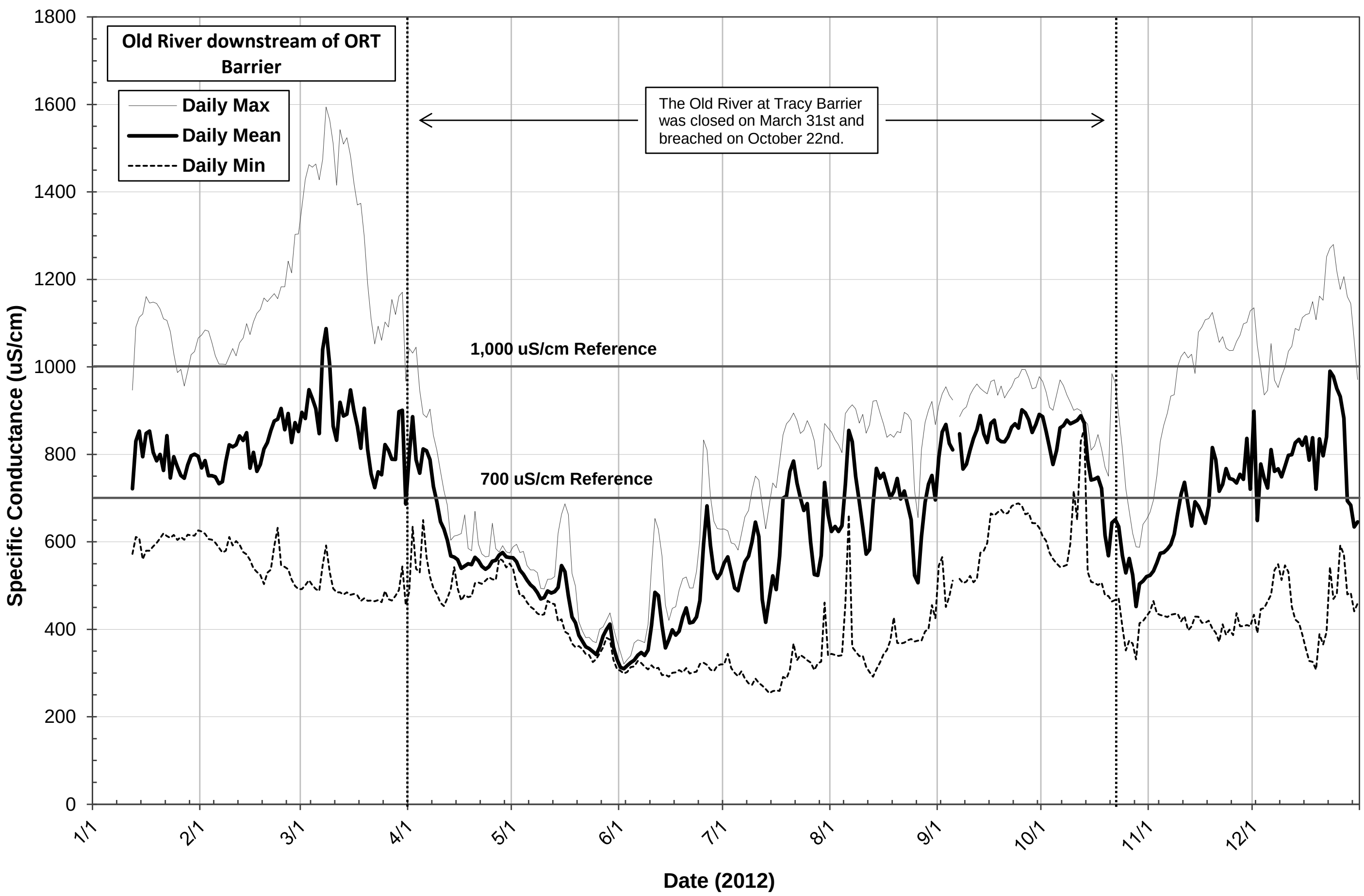


Figure 5-25: Daily Specific Conductance time-series graphs for the Old River stations

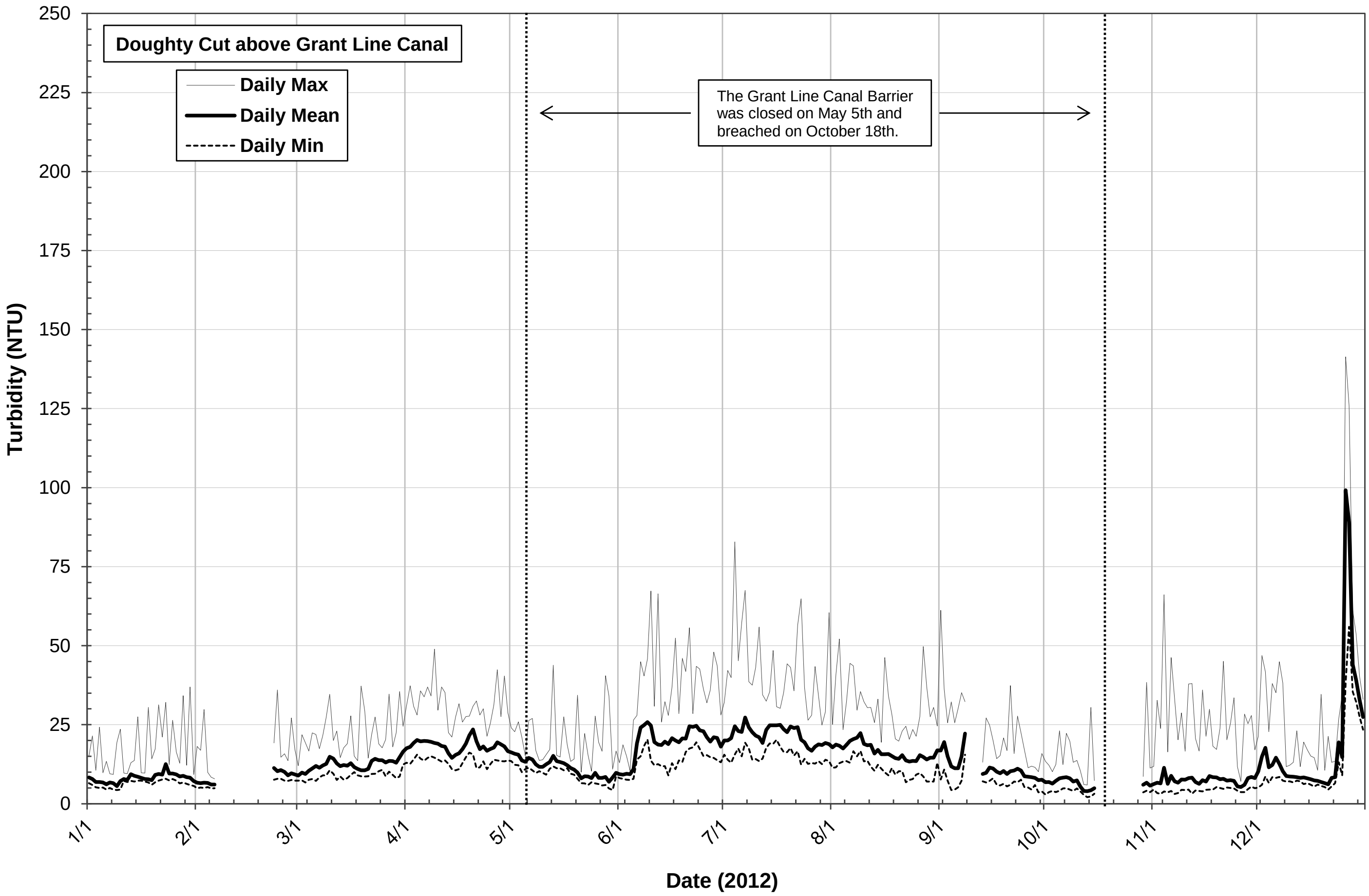
Turbidity

Turbidity in water is caused by suspended matter, such as clay, silt, organic and inorganic matter, plankton, and other microscopic organisms (APHA, 2005). Turbidity is an expression of the optical property that causes light to be scattered and absorbed rather than transmitted in straight lines through the sample (APHA, 2005). In surface waters with reduced water clarity, phytoplankton and aquatic plant growth may be adversely affected because of reduced light penetration in the water column.

Turbidity values ranged from a high of 533.8 NTU on December 24th at Middle River at Undine Road to a low of 0.1 NTU on October 15th at Grant Line Canal above Barrier (Tables 5-3 to 5-6). Figures 5-26, 5-27, and 5-28 illustrate the daily maximums, minimums, and averages for the Grant Line and Victoria Canal, Middle River, and Old River stations, respectively.

Turbidity values are usually lowest during fall in the South Delta. This was observed during 2012 with monthly average turbidity values ranging from 2.0 NTU in November at Middle River at Union Point to 11.3 in September at Doughty Cut above Grant Line Canal (Tables 5-3 to 5-6). Turbidity values were highest during winter with increased storm events.

Generally, single high turbidity spikes can be attributed to a foreign object, such as a leaf or fish passing before the optic sensors as the instrument is taking a reading. These anomalies are usually flagged as unreliable if a single value is greater than 200 NTU; however, there are times during the year where several continuous readings reveal a true event. Each South Delta station had a period of elevated turbidity values at the end of December 2012. This was most likely due to the large storm event which occurred around Christmas in 2012 leading to an increase in suspended sediment for these water bodies. There were no other obvious periods of increased turbidity readings for the rest of the year observed at the South Delta Stations.



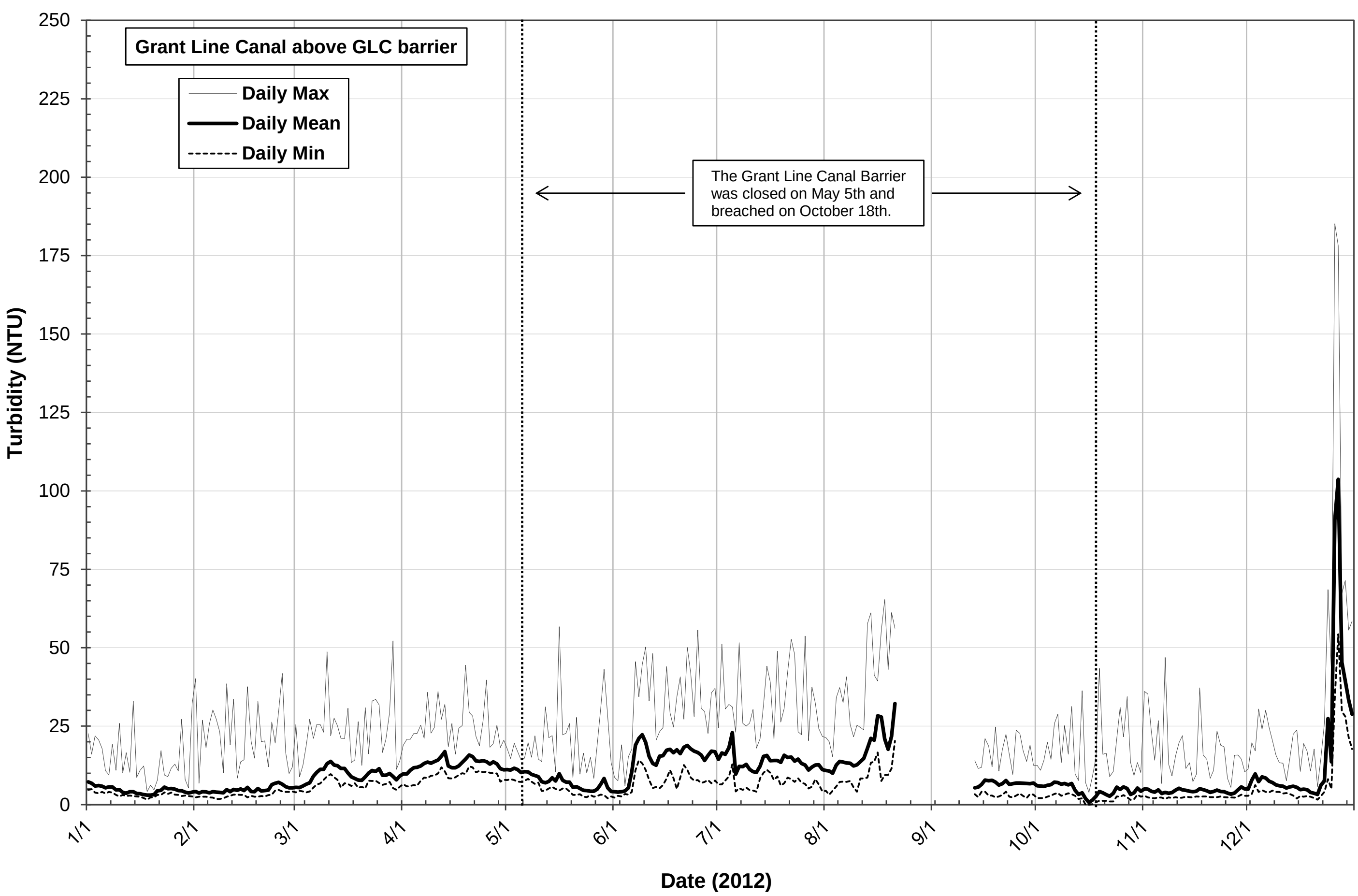
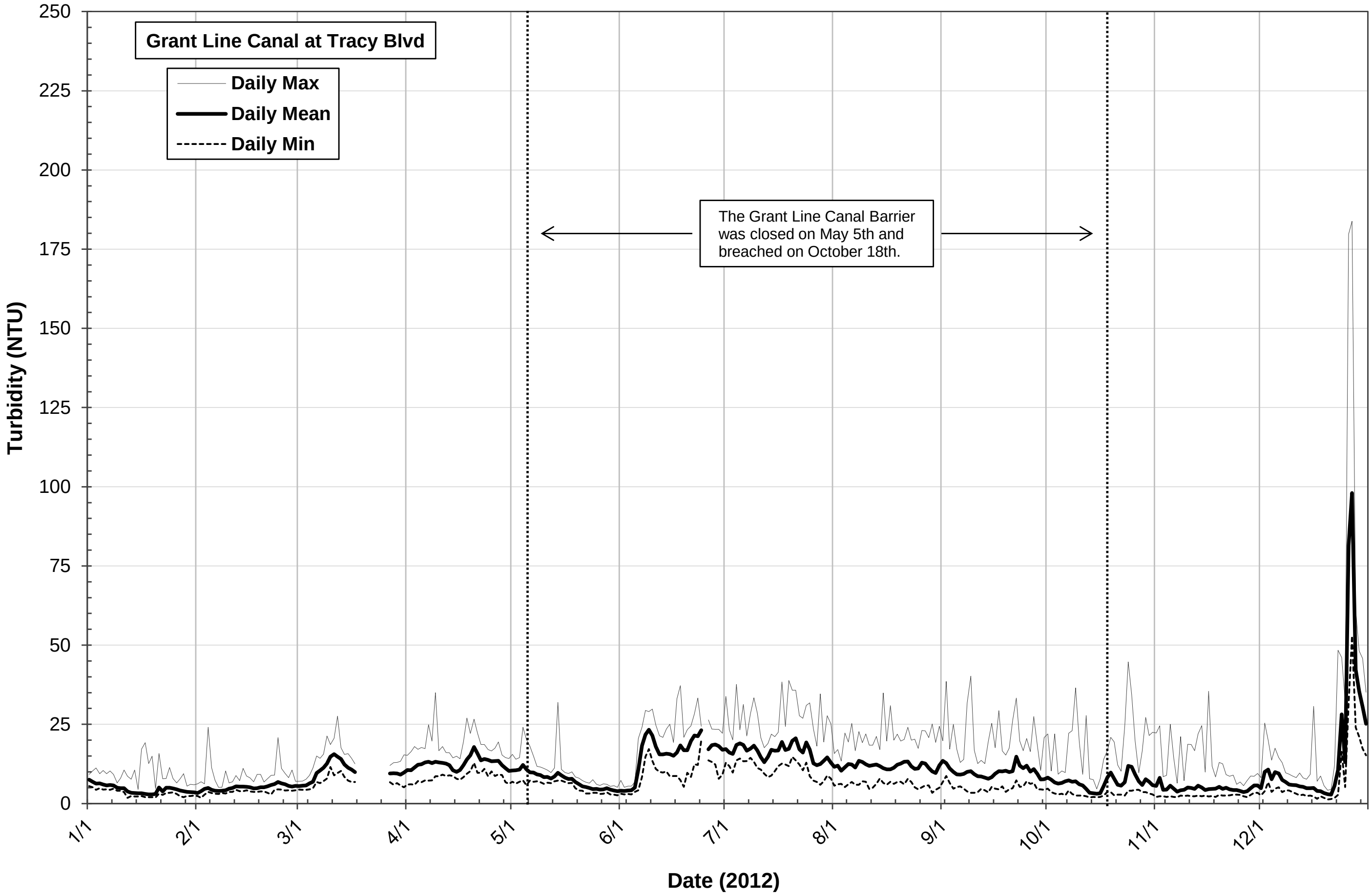


Figure 5-26: Daily Turbidity time-series graphs for the Grant Line and Victoria Canal stations



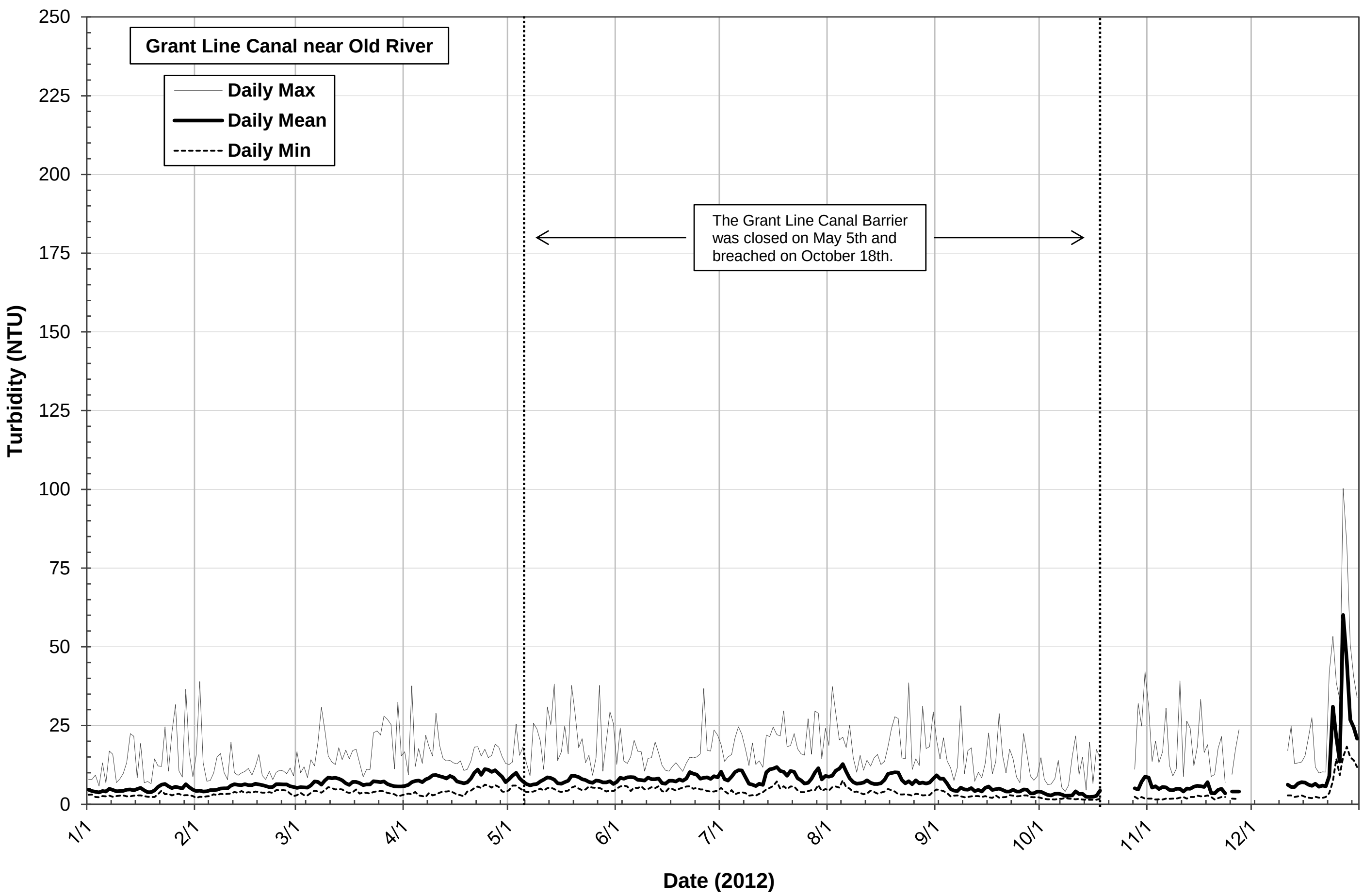


Figure 5-26: Daily Turbidity time-series graphs for the Grant Line and Victoria Canal stations

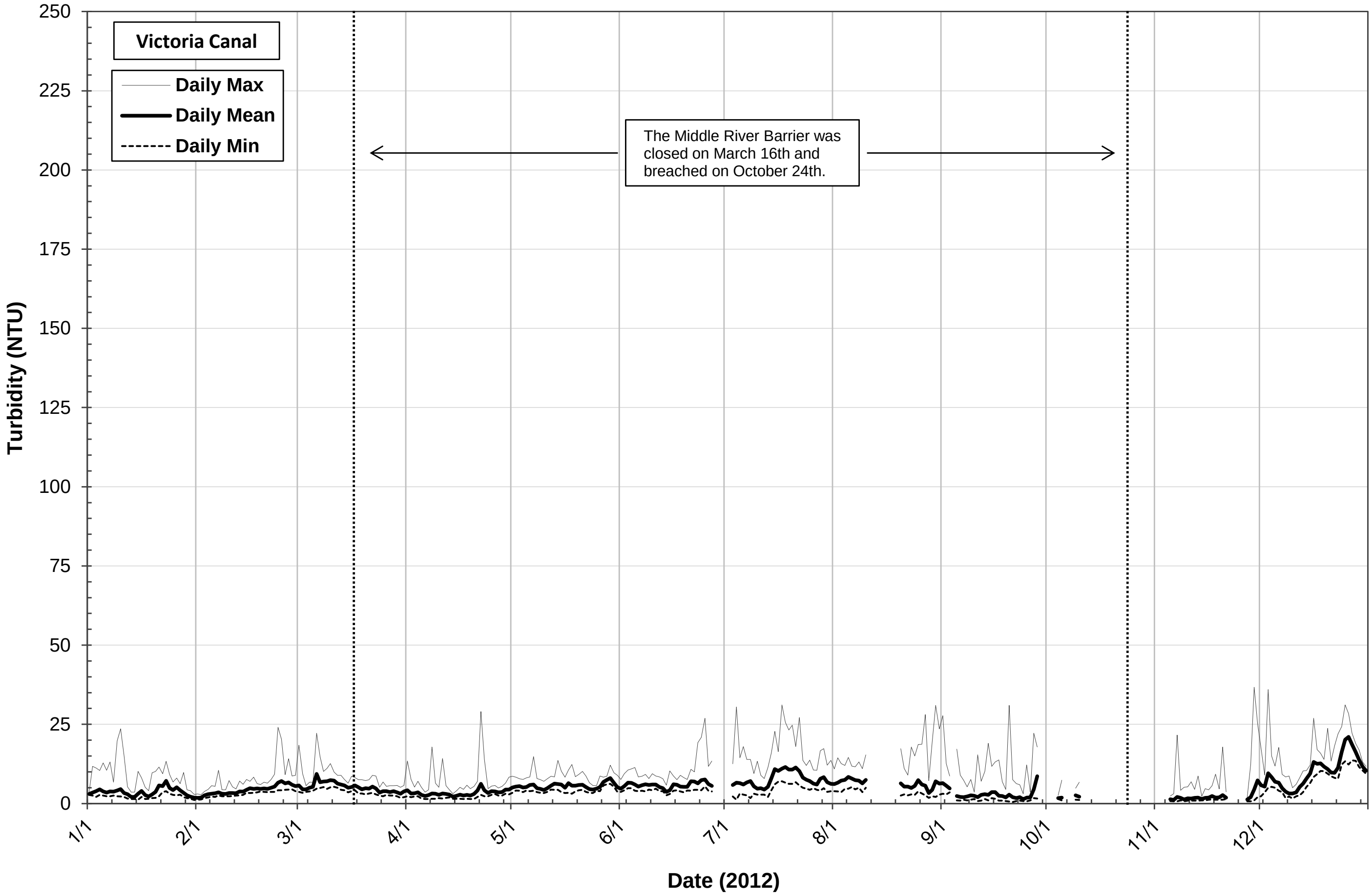
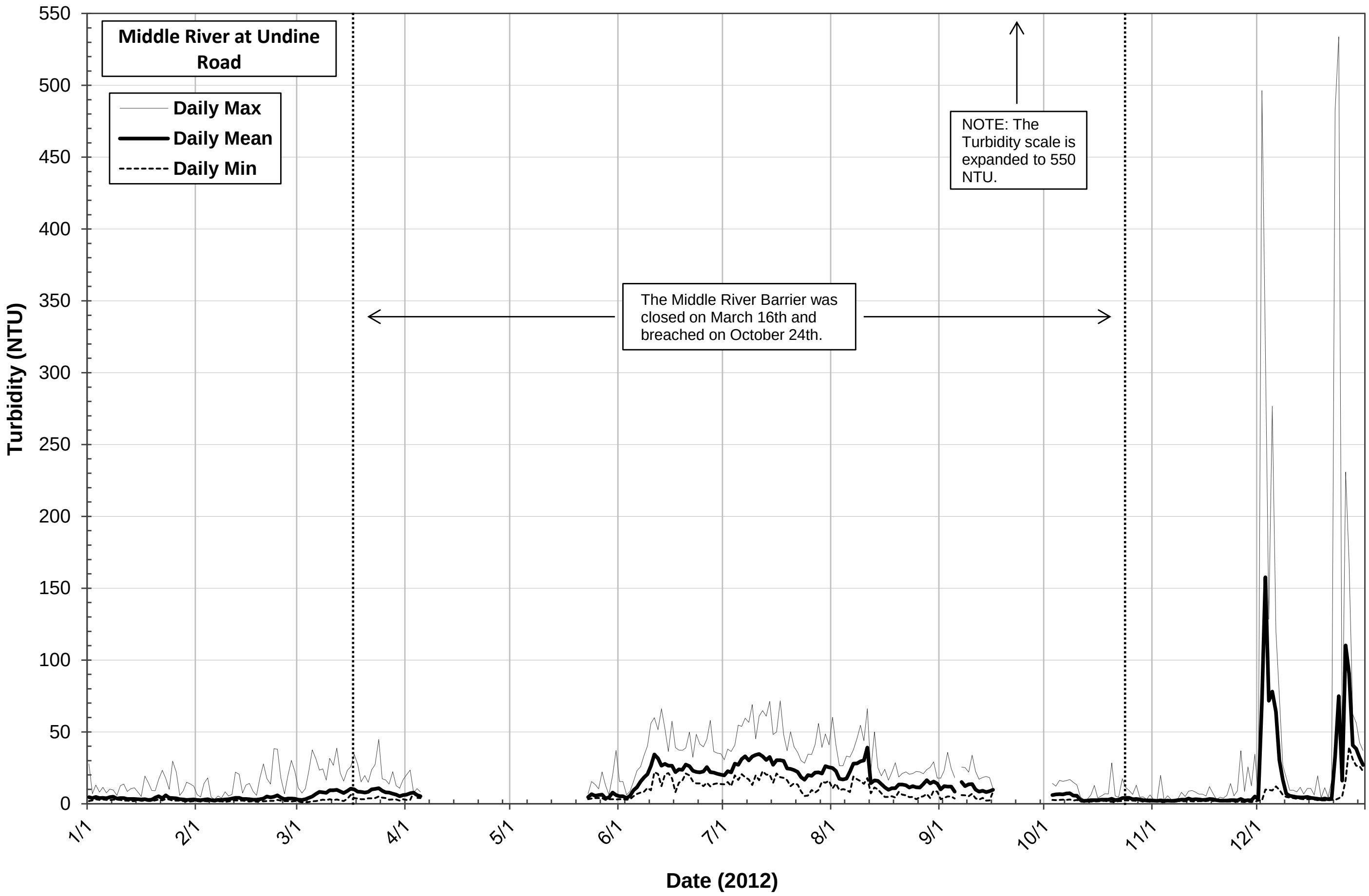


Figure 5-26: Daily Turbidity time-series graphs for the Grant Line and Victoria Canal stations



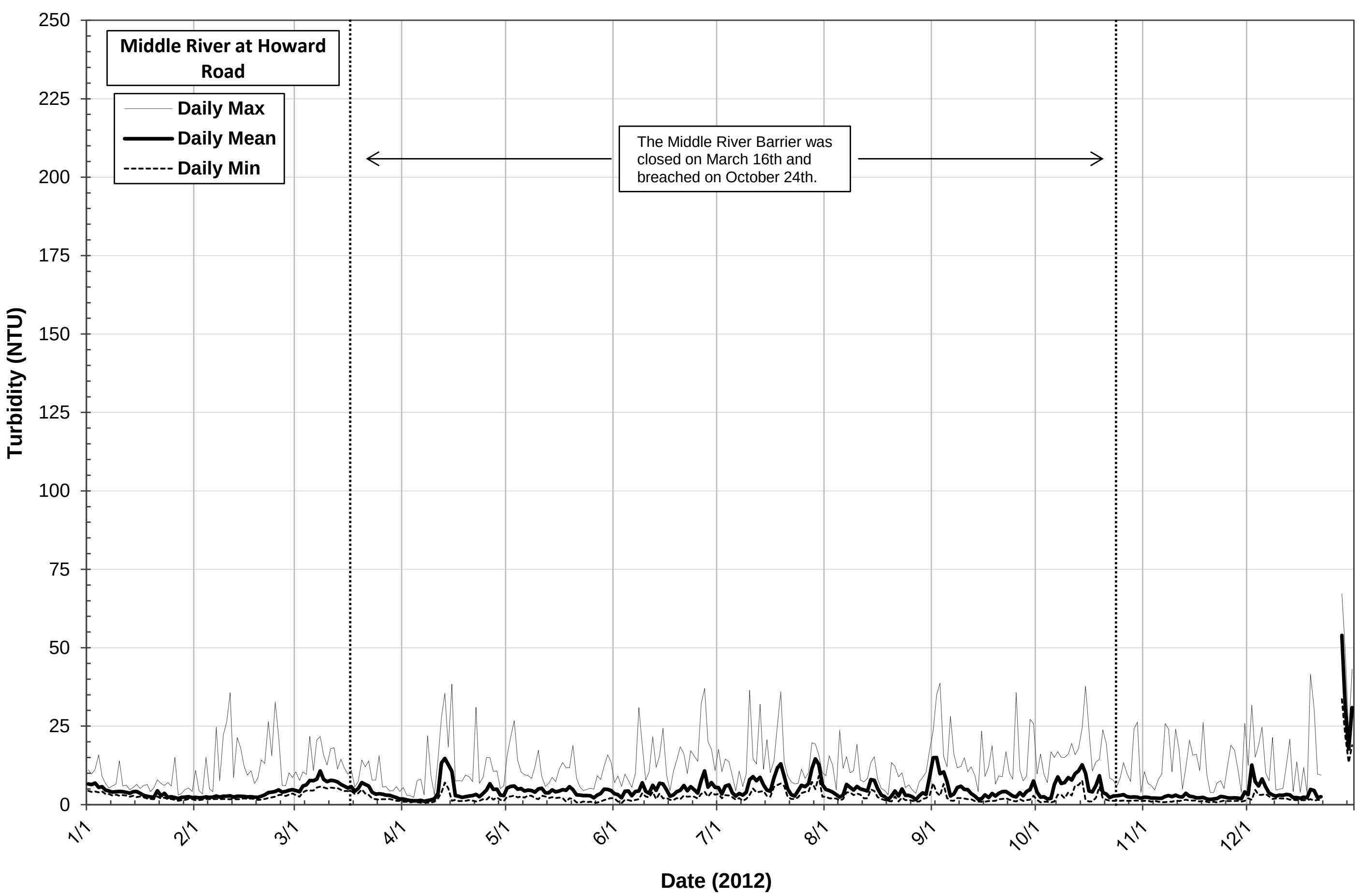
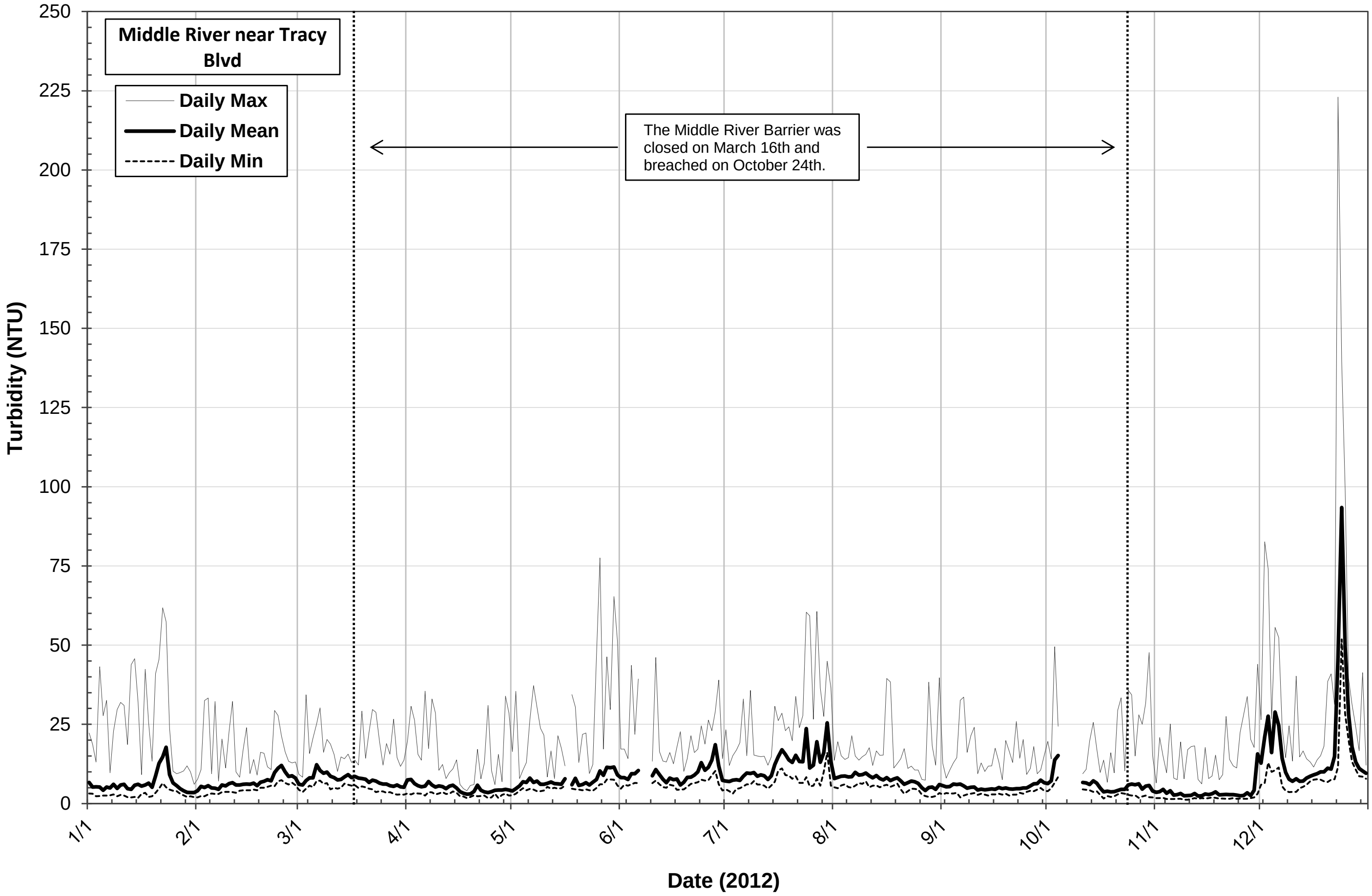


Figure 5-27: Daily Turbidity time-series graphs for the Middle River stations



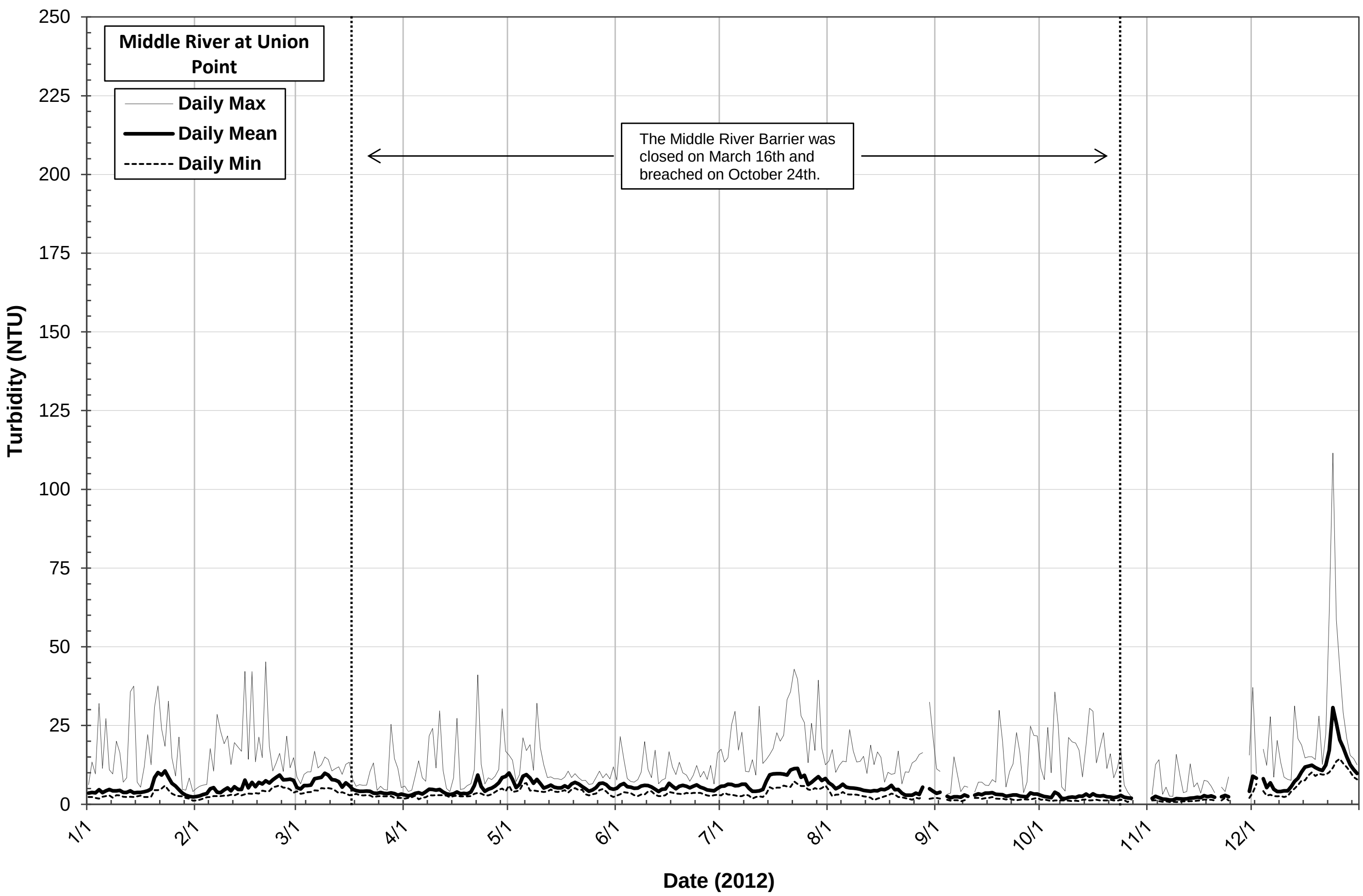
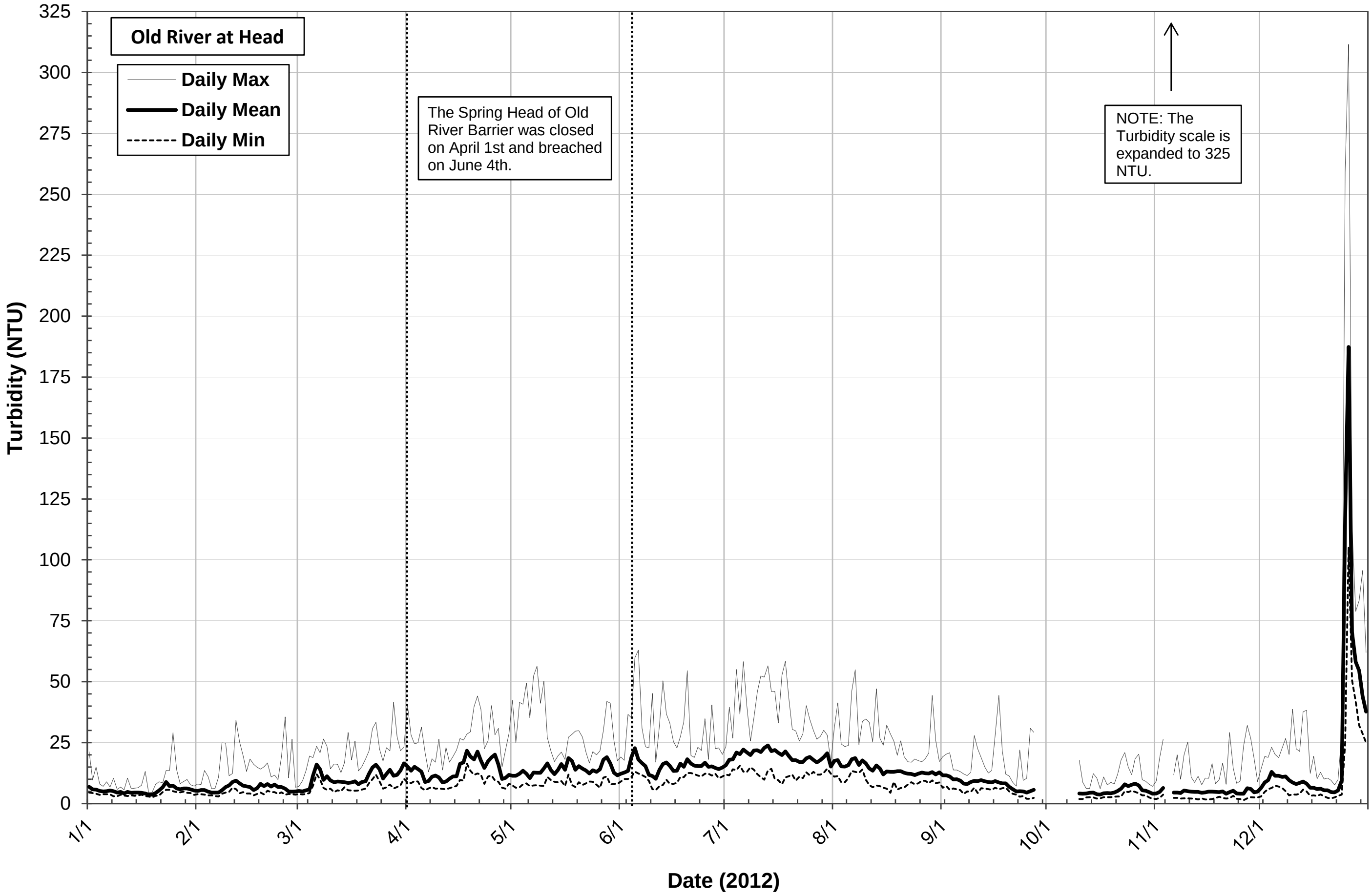


Figure 5-27: Daily Turbidity time-series graphs for the Middle River stations



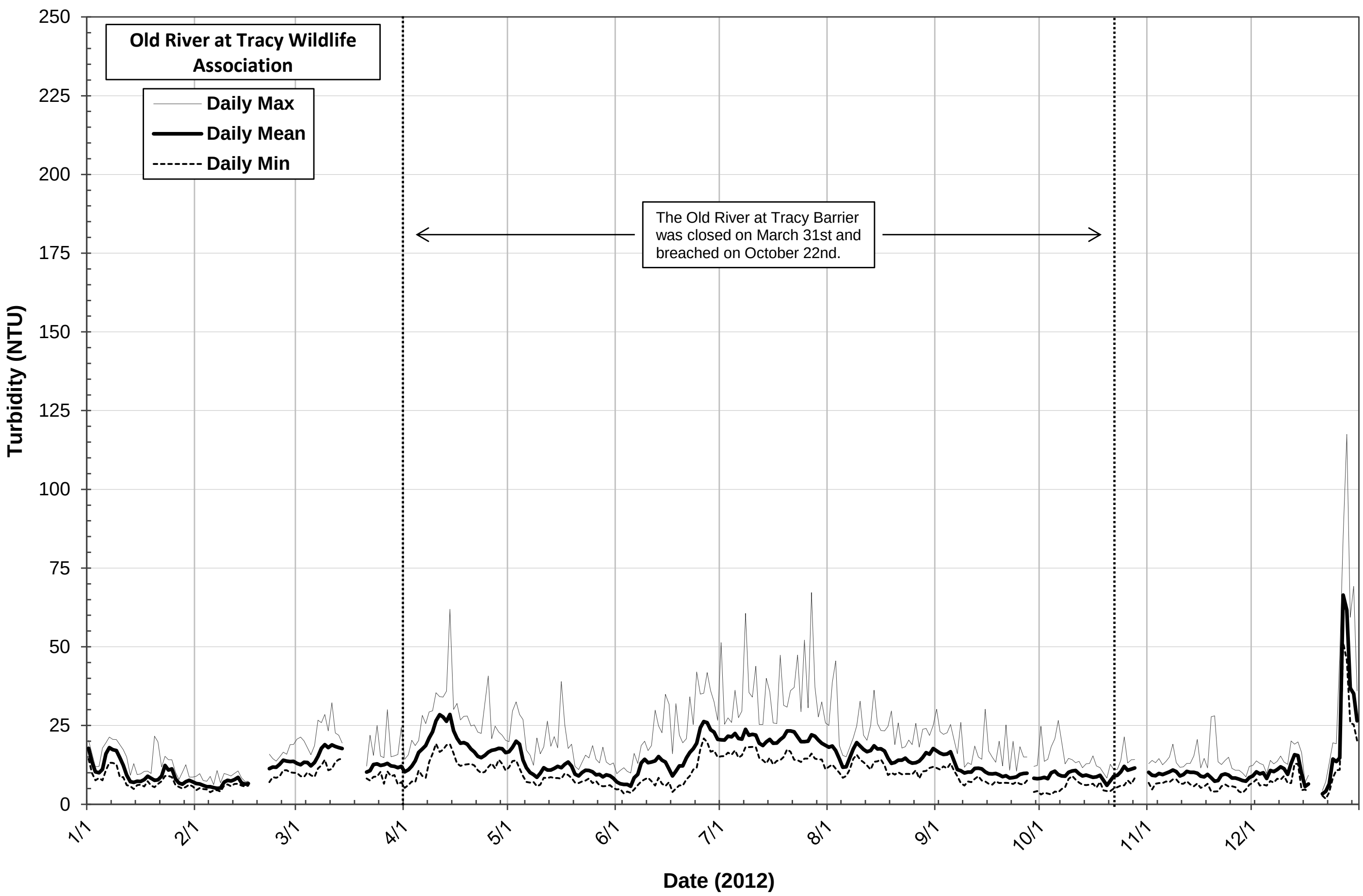
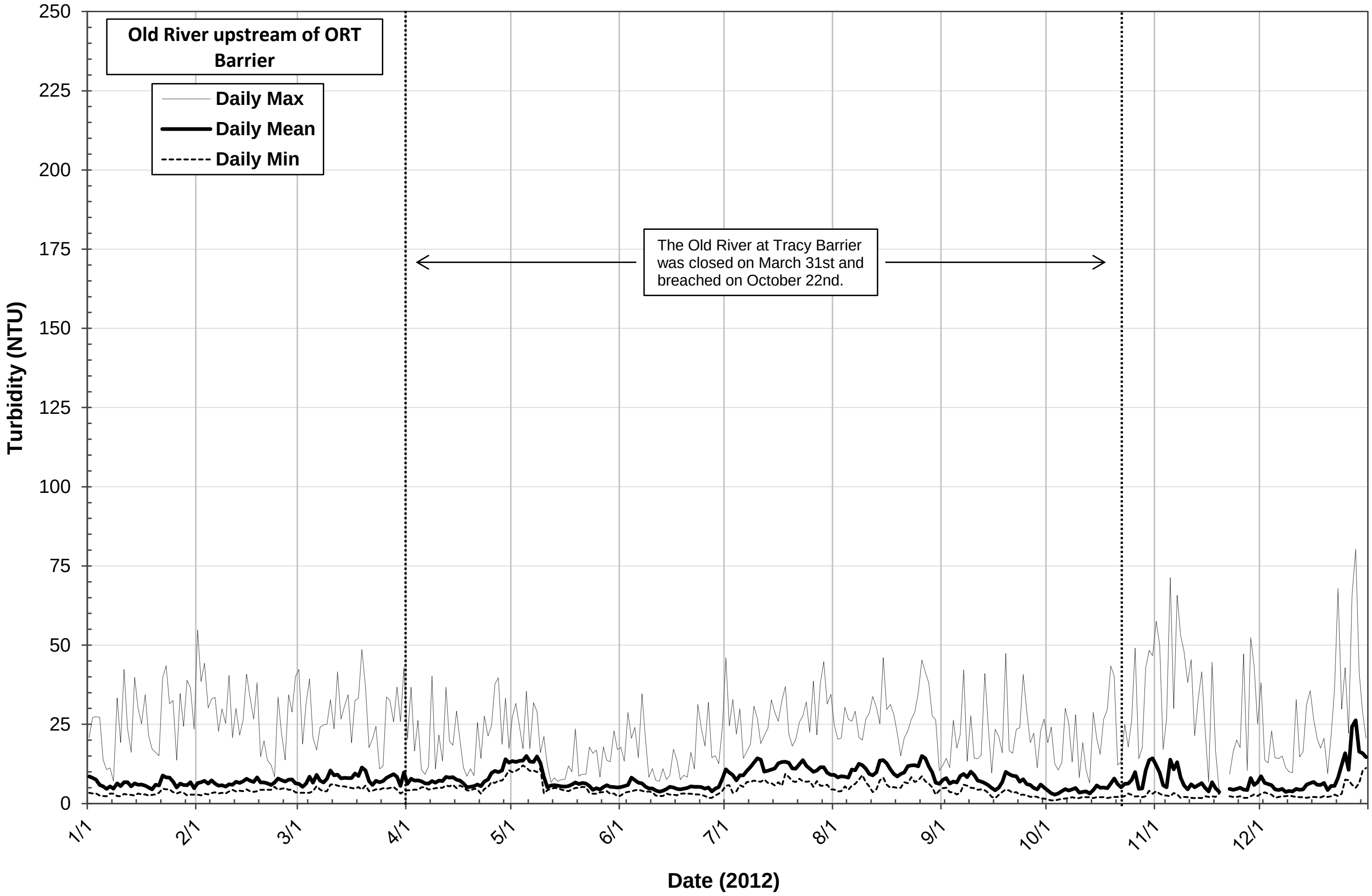


Figure 5-28: Daily Turbidity time-series graphs for the Old River stations



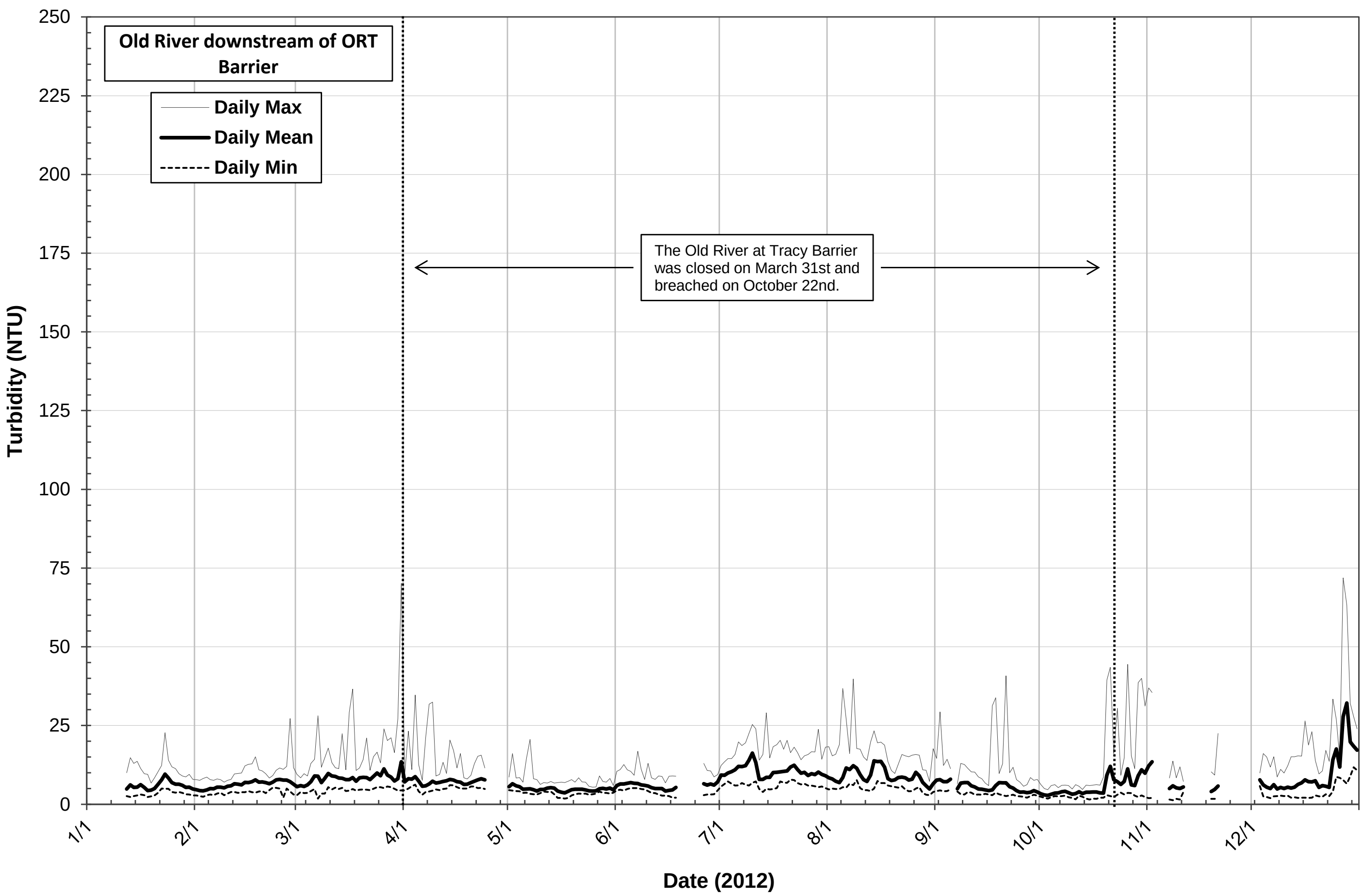


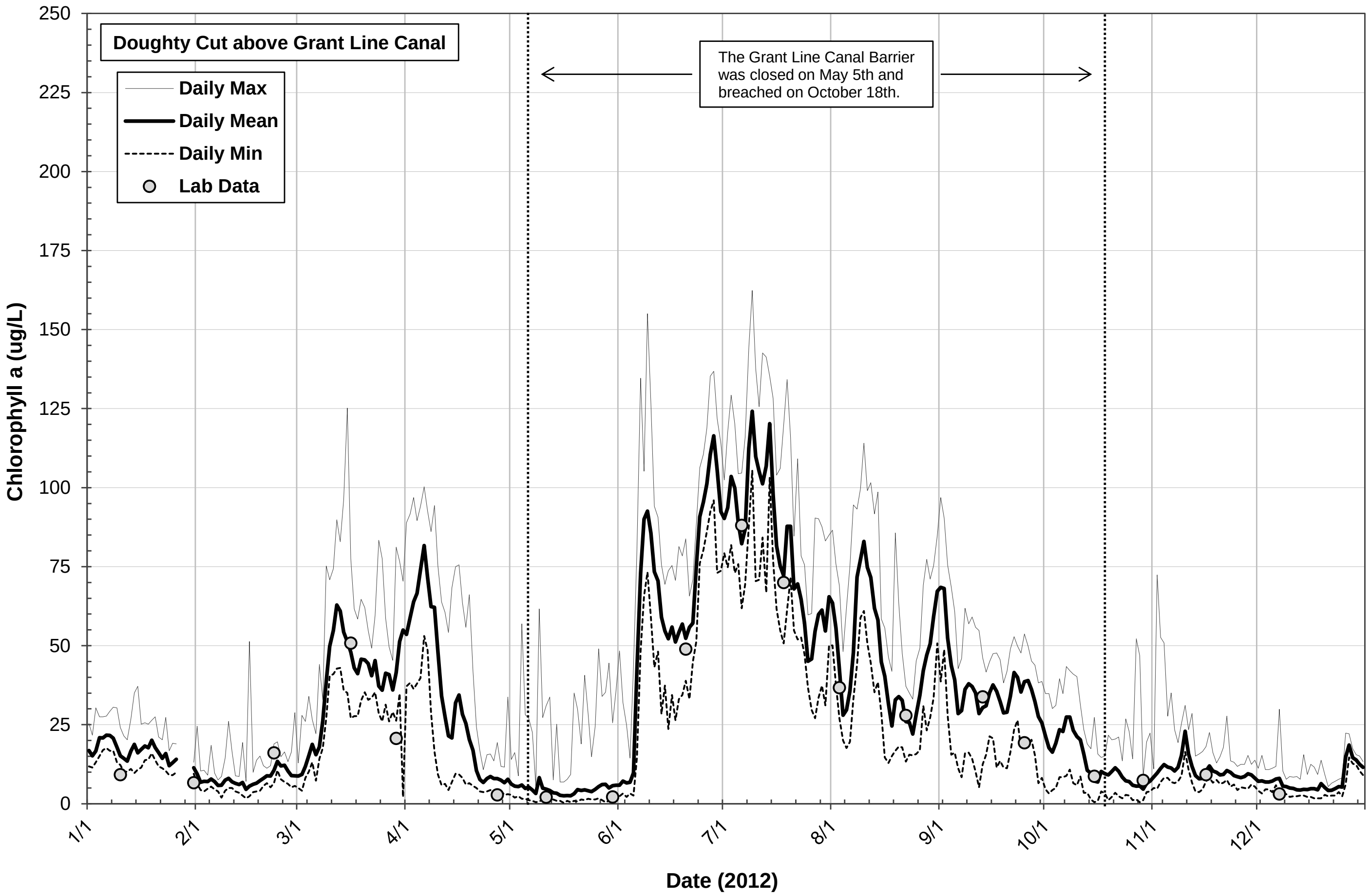
Figure 5-28: Daily Turbidity time-series graphs for the Old River stations

Chlorophyll *a*

Chlorophyll *a* concentrations can be used as an indicator of phytoplankton biomass in a water body (APHA, 2005). Phytoplankton (microscopic algae) occur as unicellular, colonial, or filamentous forms and are primarily grazed upon by zooplankton and other aquatic organisms (APHA, 2005). The species composition and/or biomass of phytoplankton may be a useful tool in assessing water quality (APHA, 2005). Algae can influence water quality by affecting: pH, dissolved oxygen, turbidity, the color, taste and odor of water, and under certain conditions, some species can develop noxious blooms.

Staff adjusted the chlorophyll *a* concentrations measured by the optical probes by using the procedures discussed in the Materials and Methods section of this chapter. Adjusted chlorophyll *a* concentrations ranged from a high of 335.6 µg/L on July 14th at Old River at Tracy Wildlife Association to a low of 0.0 µg/L on January 29th at Middle River at Howard Road (Tables 5-3 to 5-6). Figures 5-29, 5-30, and 5-31 illustrate the daily maximums, minimums, and averages for the Grant Line and Victoria Canal, Middle River, and Old River stations, respectively.

Chlorophyll *a* concentrations increased during spring and summer months, which is typical in the South Delta. Most of the South Delta stations had two periods of elevated adjusted chlorophyll *a* concentrations: once in spring from March through April and the other ranged from June till September. Monthly average adjusted chlorophyll *a* concentrations during the spring season (March-May) ranged from 3.8 µg/L in May at Grant Line Canal near Old River to 116.3 µg/L in April at Old River at Tracy Wildlife Association (Tables 5-3 to 5-6). Monthly average adjusted chlorophyll *a* concentrations during the summer and early fall season (June-September) ranged from 2.2 µg/L in September at Grant Line Canal near Old River to 142.3 µg/L in July at Old River at Tracy Wildlife Association. Victoria Canal, Middle River and Union Point, and Middle River near Tracy Blvd remained relatively constant with an average of approximately 4 µg/L in 2012 except with a slight peak during July.



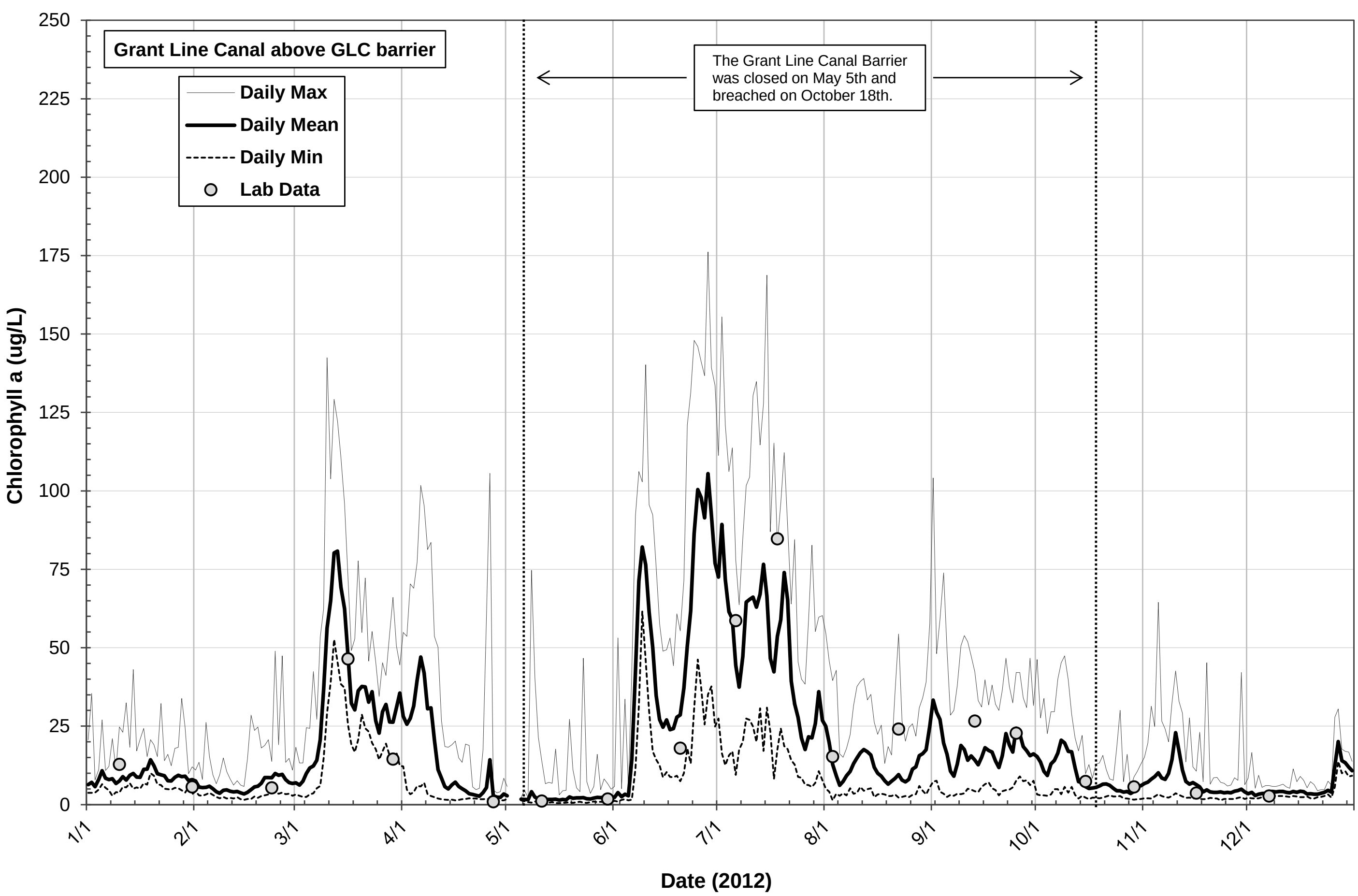
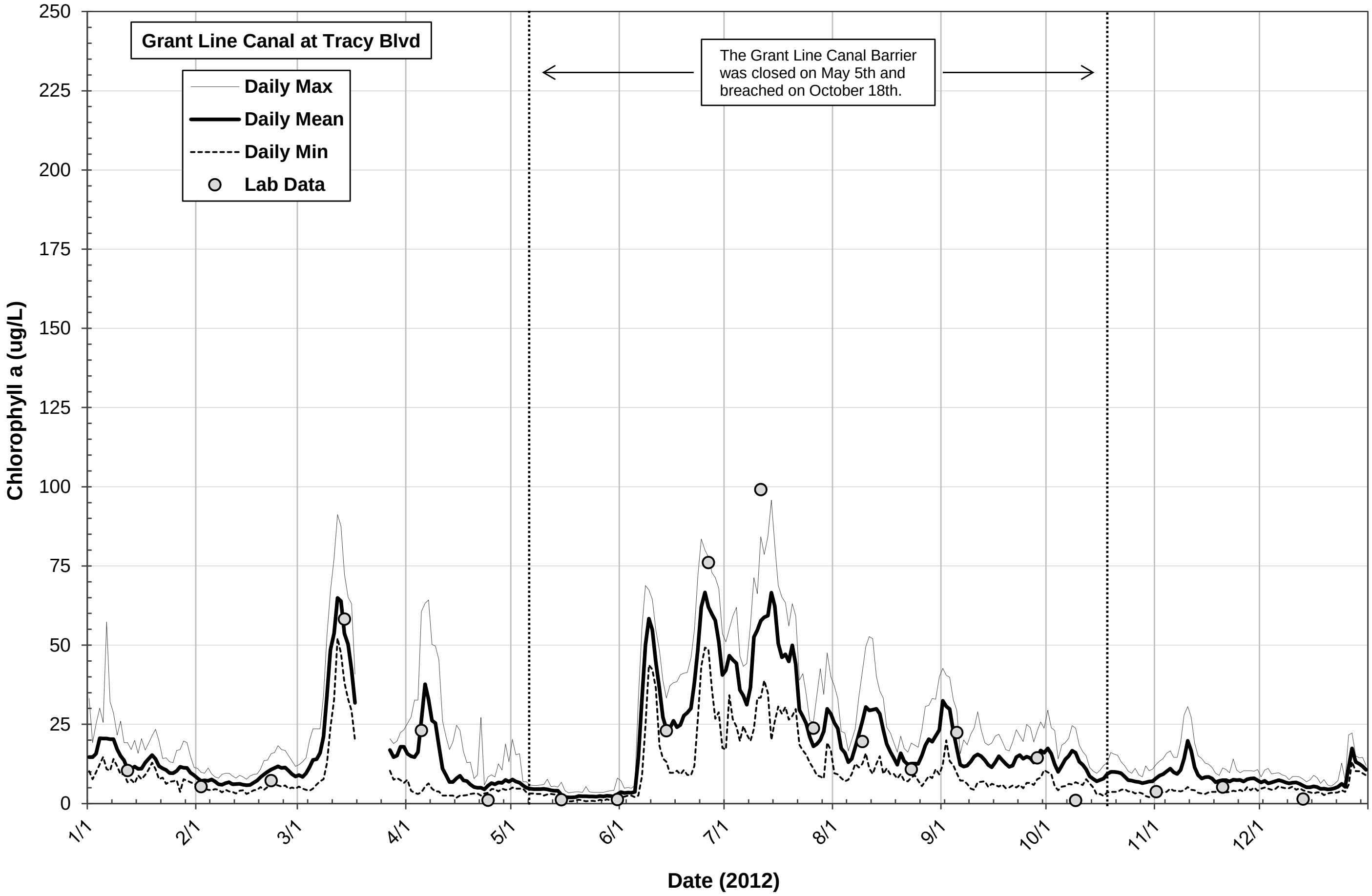


Figure 5-29: Daily Chlorophyll *a* time-series graphs for the Grant Line and Victoria Canal stations



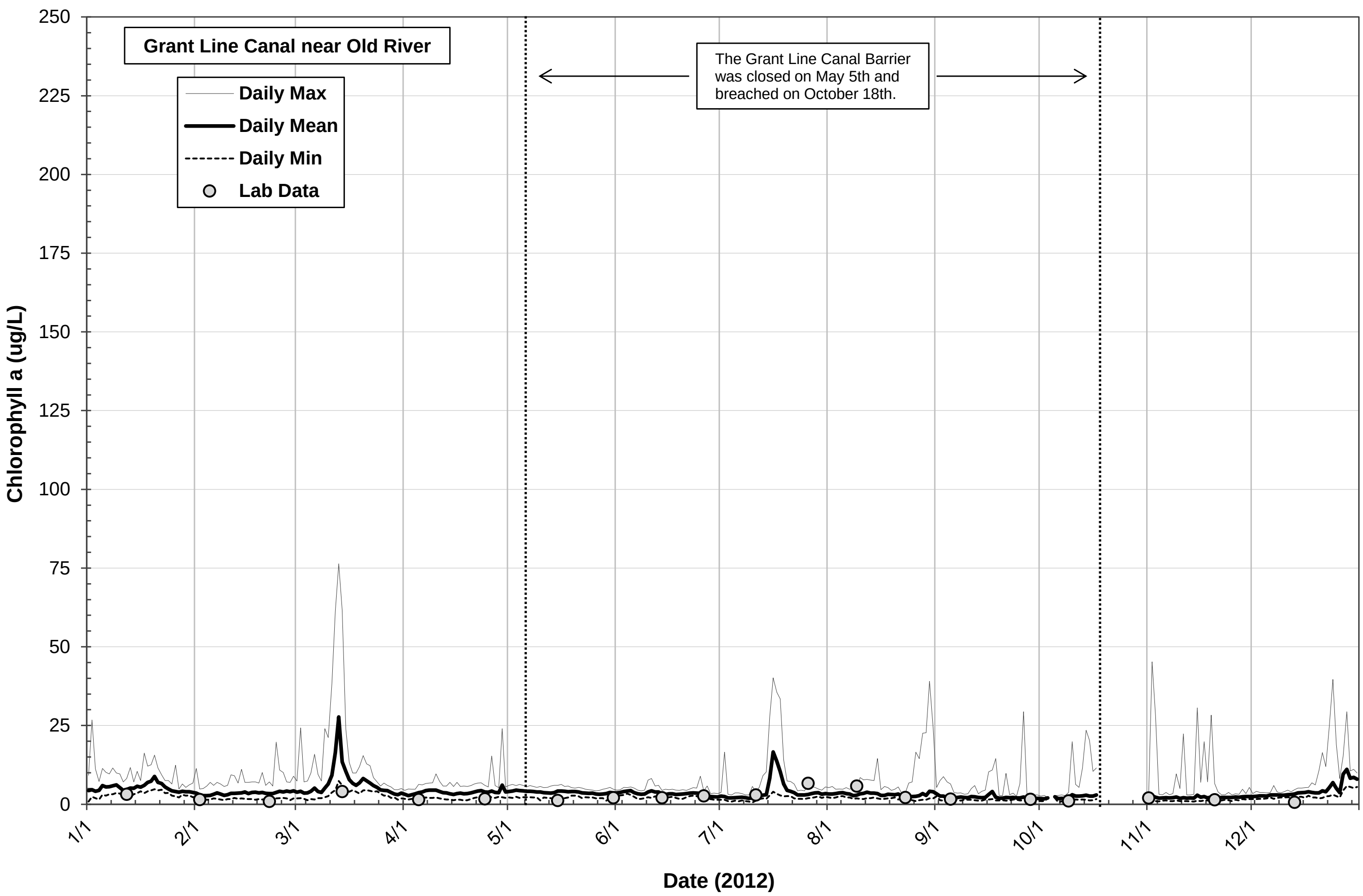


Figure 5-29: Daily Chlorophyll *a* time-series graphs for the Grant Line and Victoria Canal stations

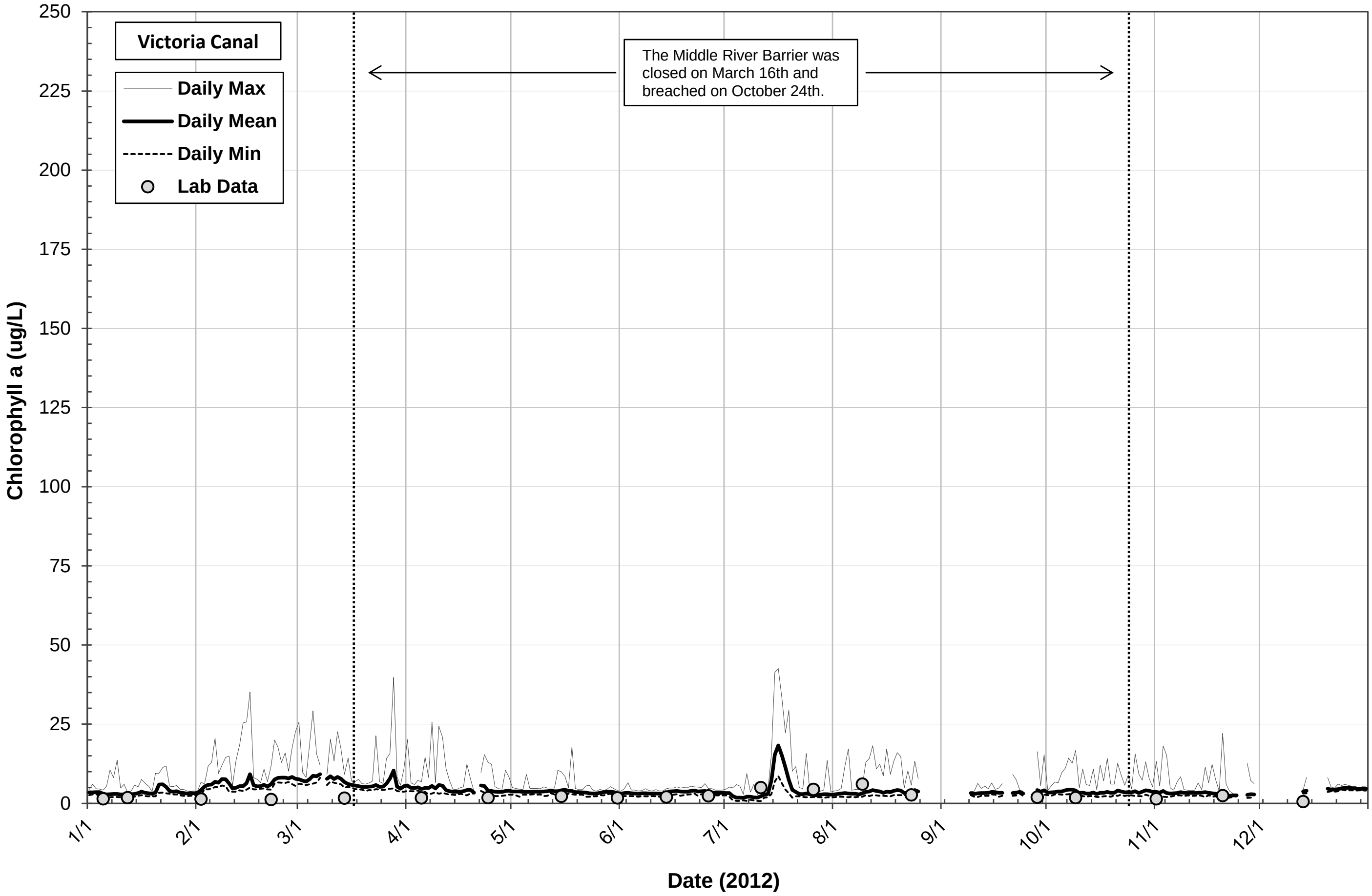
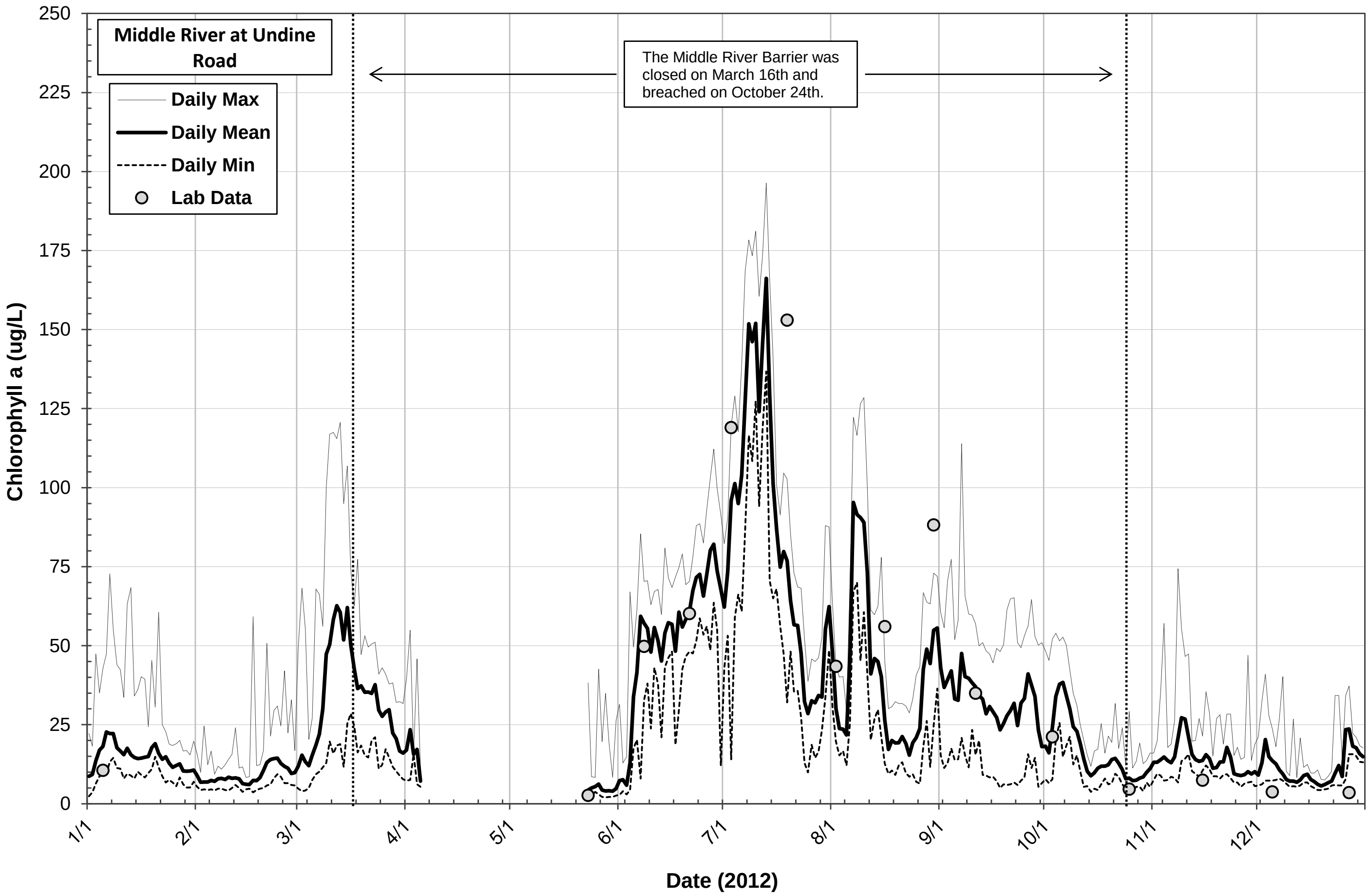


Figure 5-29: Daily Chlorophyll *a* time-series graphs for the Grant Line and Victoria Canal stations



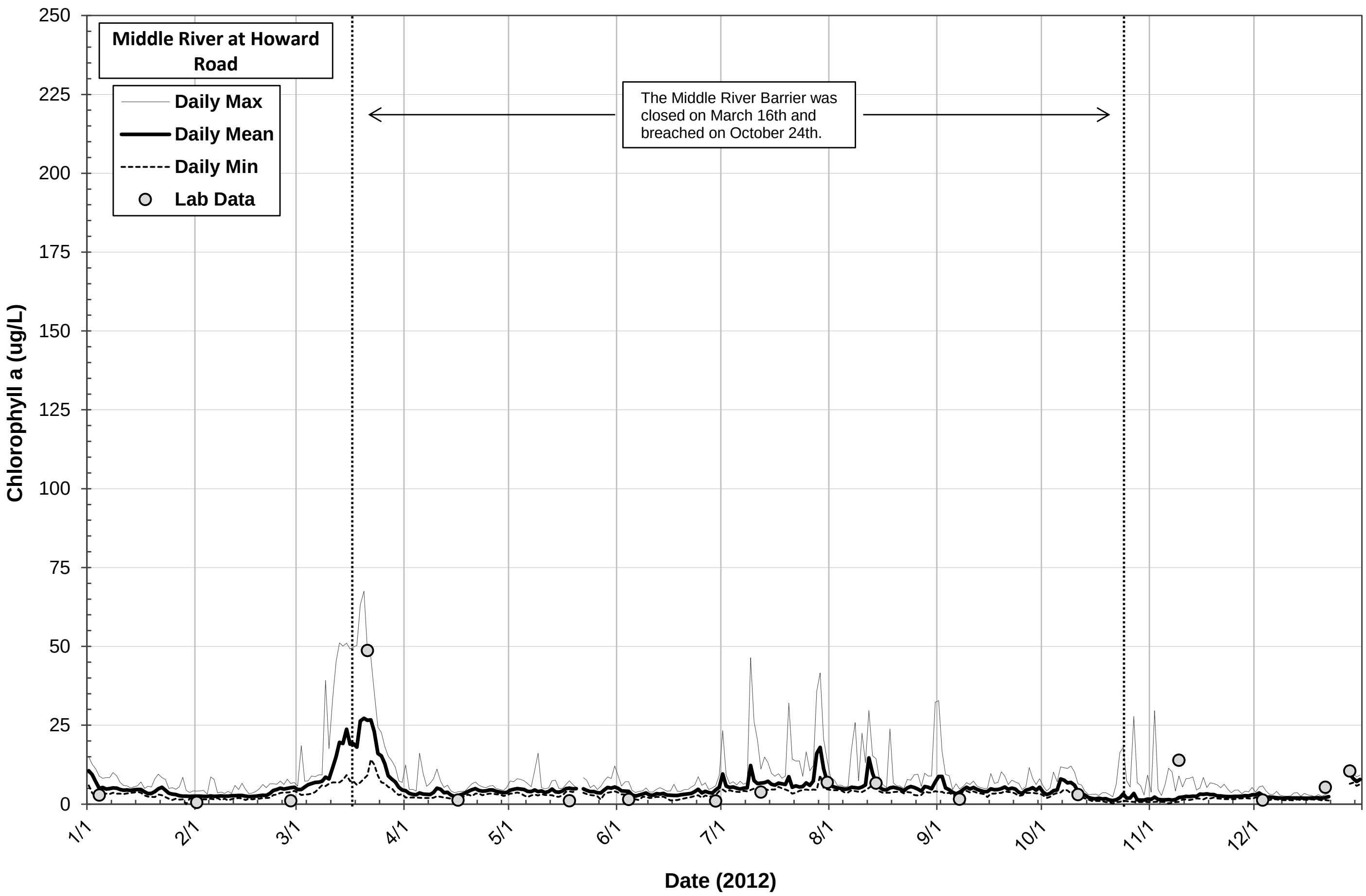
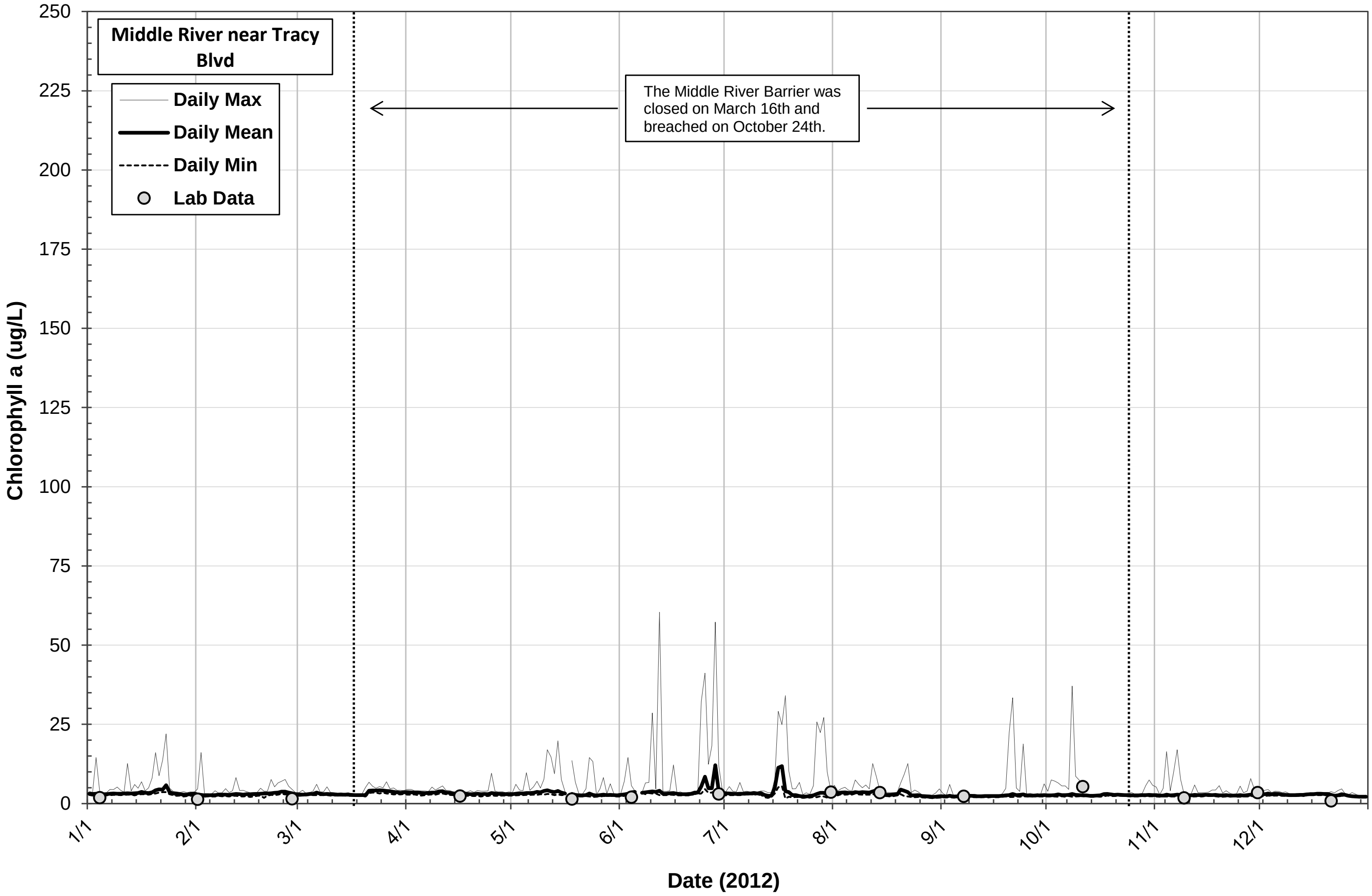


Figure 5-30: Daily Chlorophyll *a* time-series graphs for the Middle River stations



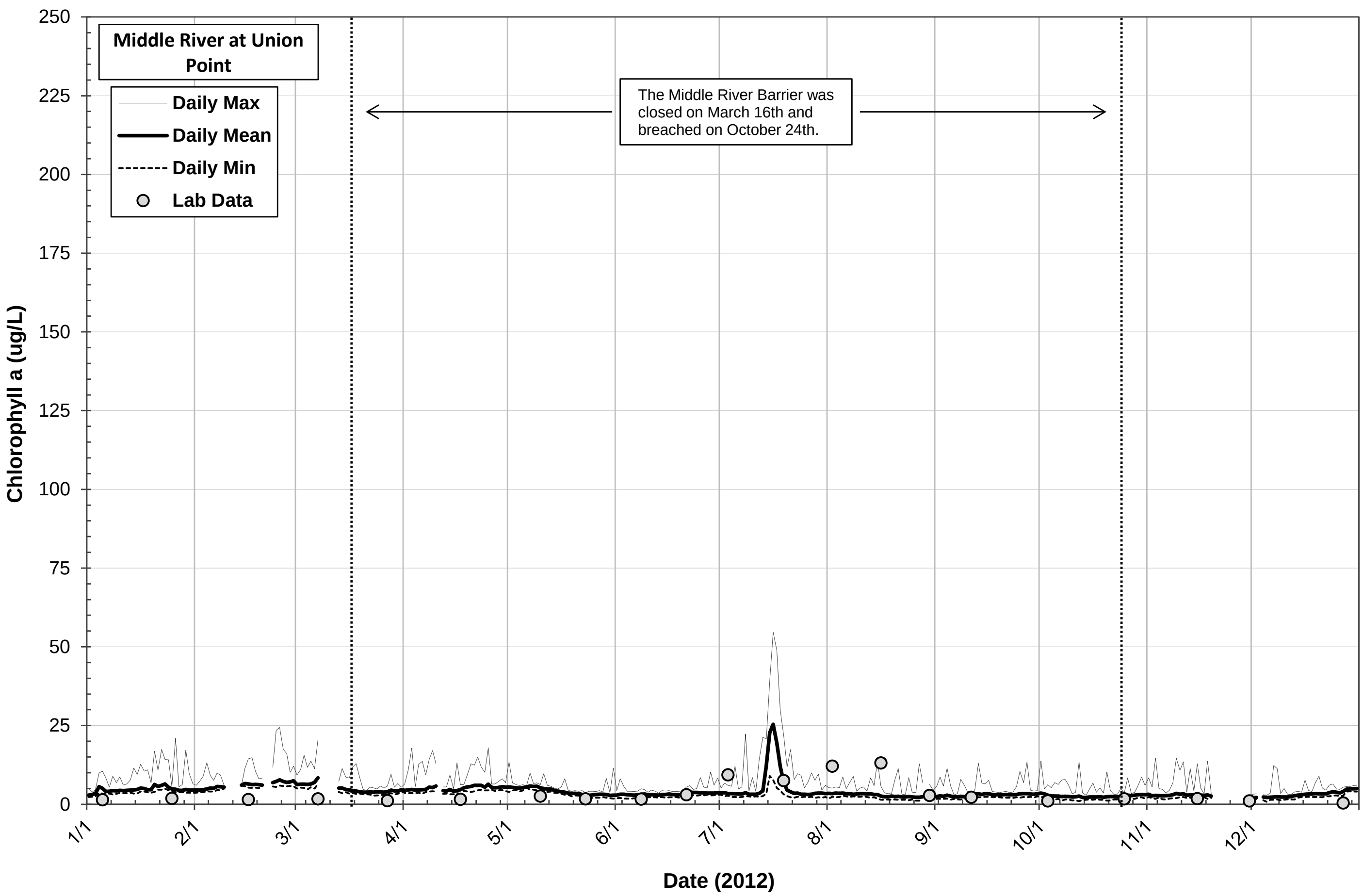
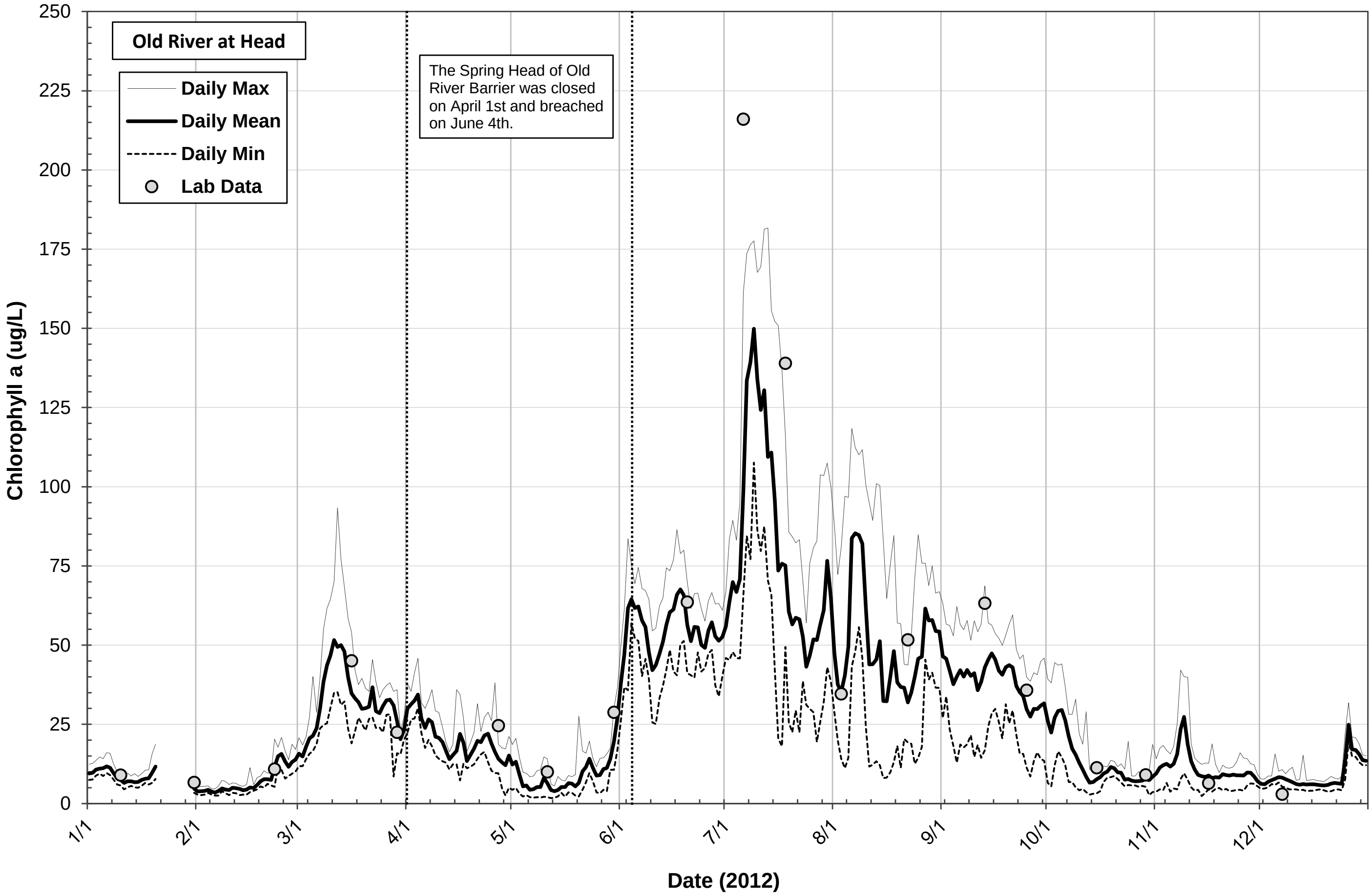


Figure 5-30: Daily Chlorophyll *a* time-series graphs for the Middle River stations



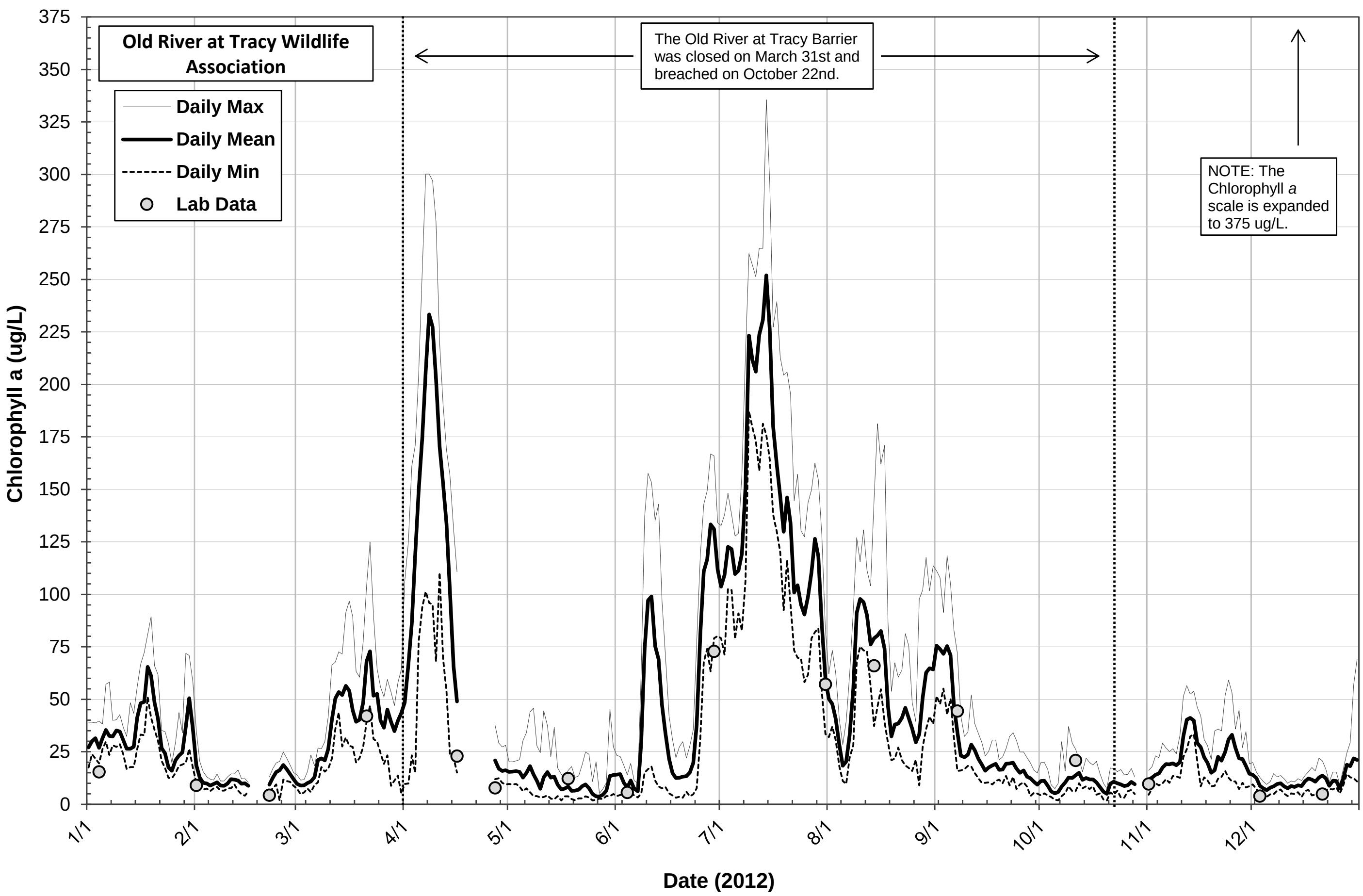
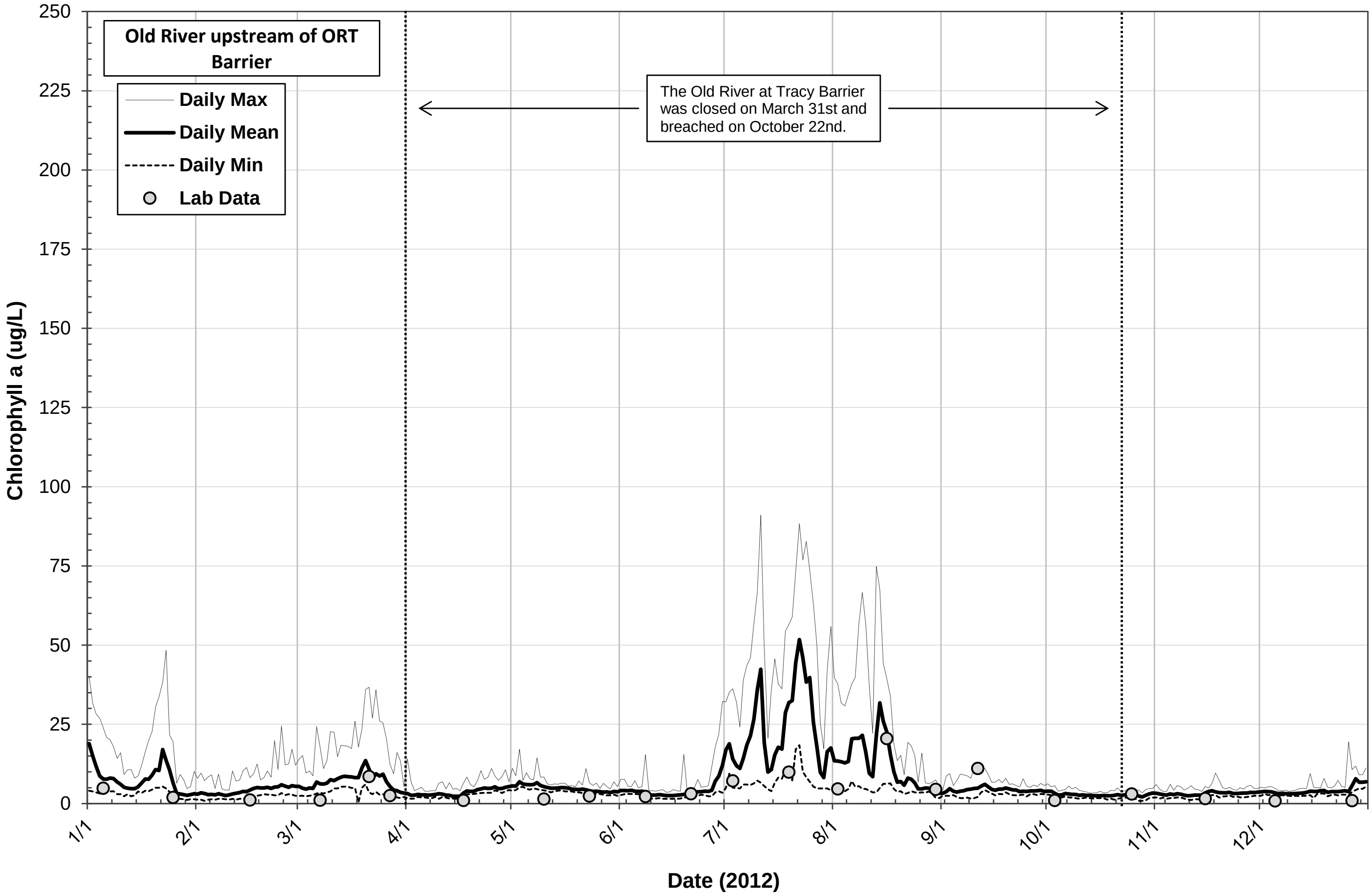


Figure 5-31: Daily Chlorophyll *a* time-series graphs for the Old River stations



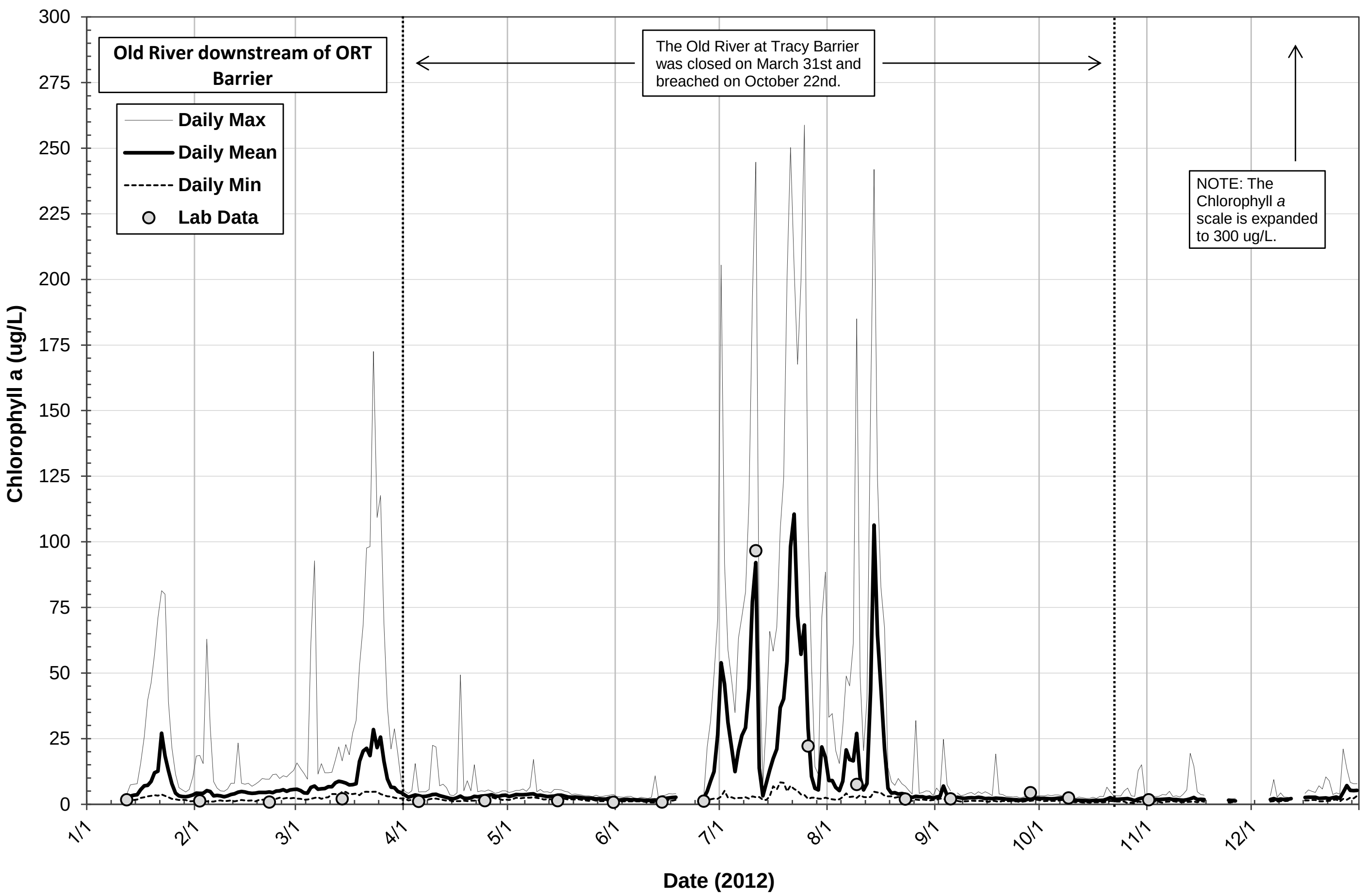


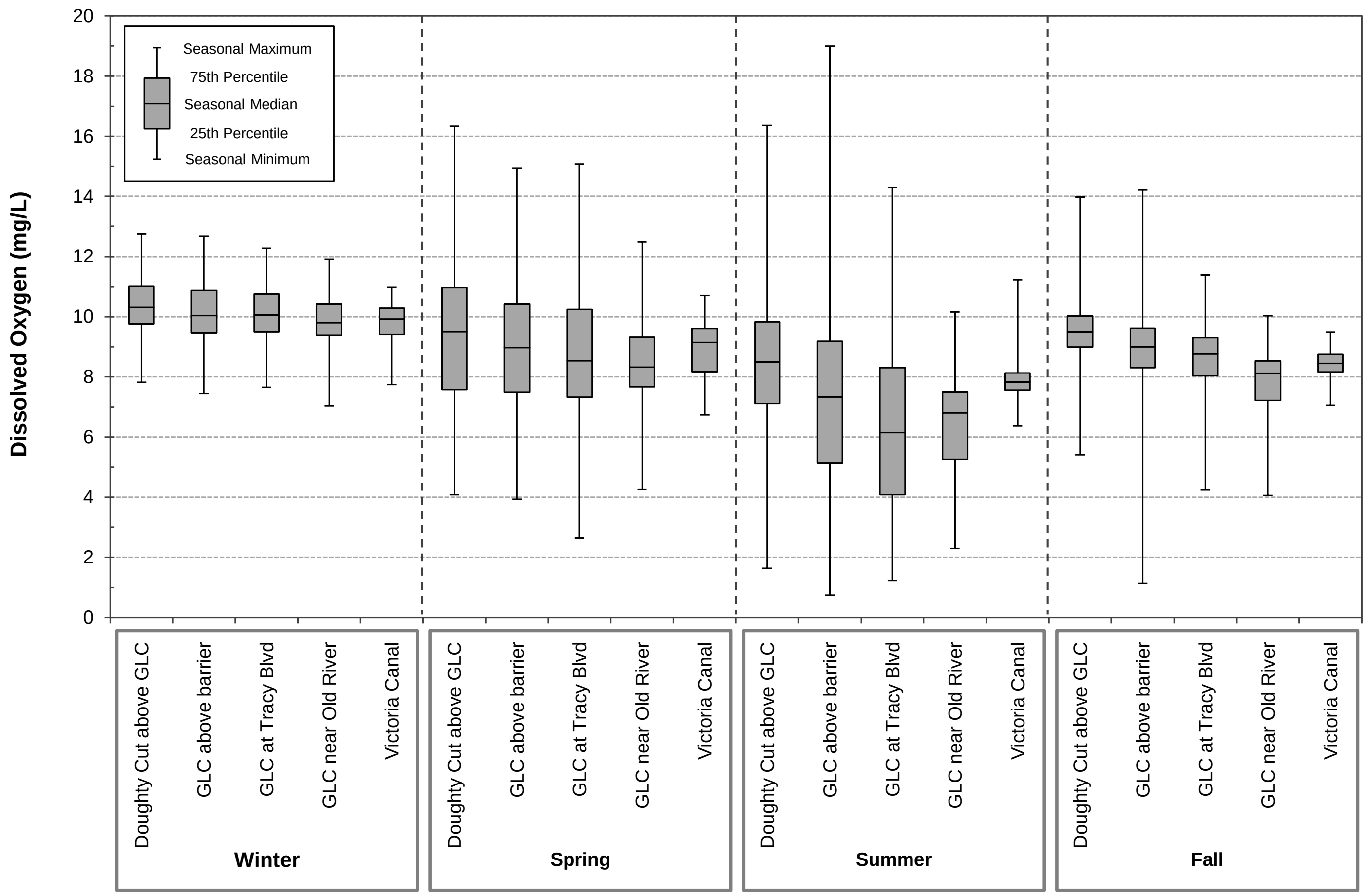
Figure 5-31: Daily Chlorophyll *a* time-series graphs for the Old River stations

DISCUSSION

Box plots illustrating the seasonal maximums and minimums, 25th and 75th percentiles, and medians for each constituent measured at the Grant Line and Victoria Canal, Middle River, and Old River stations are shown in Figures 5-32, 5-33, and 5-34, respectively. Overall trends in the 2012 water quality data collected in the South Delta are discussed below:

- A visual comparison of the 2012 water temperature plots for the South Delta monitoring sites revealed similar trends among all of the stations. This similarity is in part attributable to a common geographic location and similar meteorological conditions. Even though the sites are close to each other, variations do occur from flow, tides, barrier operation, local discharges, and bathymetry.
- Variation observed in specific conductance was due in part to differences in source water, flow dynamics, agricultural pumping, and agricultural return flows. South Delta stations with lower conductivity values throughout the year tended to be more influenced by water from the Sacramento River.
- Chlorophyll *a* concentrations can indicate whether or not algal photosynthesis is occurring in the water nearby; higher chlorophyll *a* concentrations are indicative of higher rates of photosynthesis. Greater rates of algal photosynthesis in the water can have an effect on pH levels and dissolved oxygen concentrations. The South Delta stations with higher chlorophyll *a* values tended to have higher pH values with more variability. Dissolved oxygen concentrations were also more variable with periods of supersaturation and very low levels at the stations with higher chlorophyll *a* values.
- Turbidity values at the South Delta stations were site-specific with some stations having higher or lower turbidity along the same waterbody. Stations that were more influenced by the water from the Sacramento River tended to have lower turbidity values throughout the year.

A more specific discussion of the water quality trends in 2012 for each waterbody is presented below.



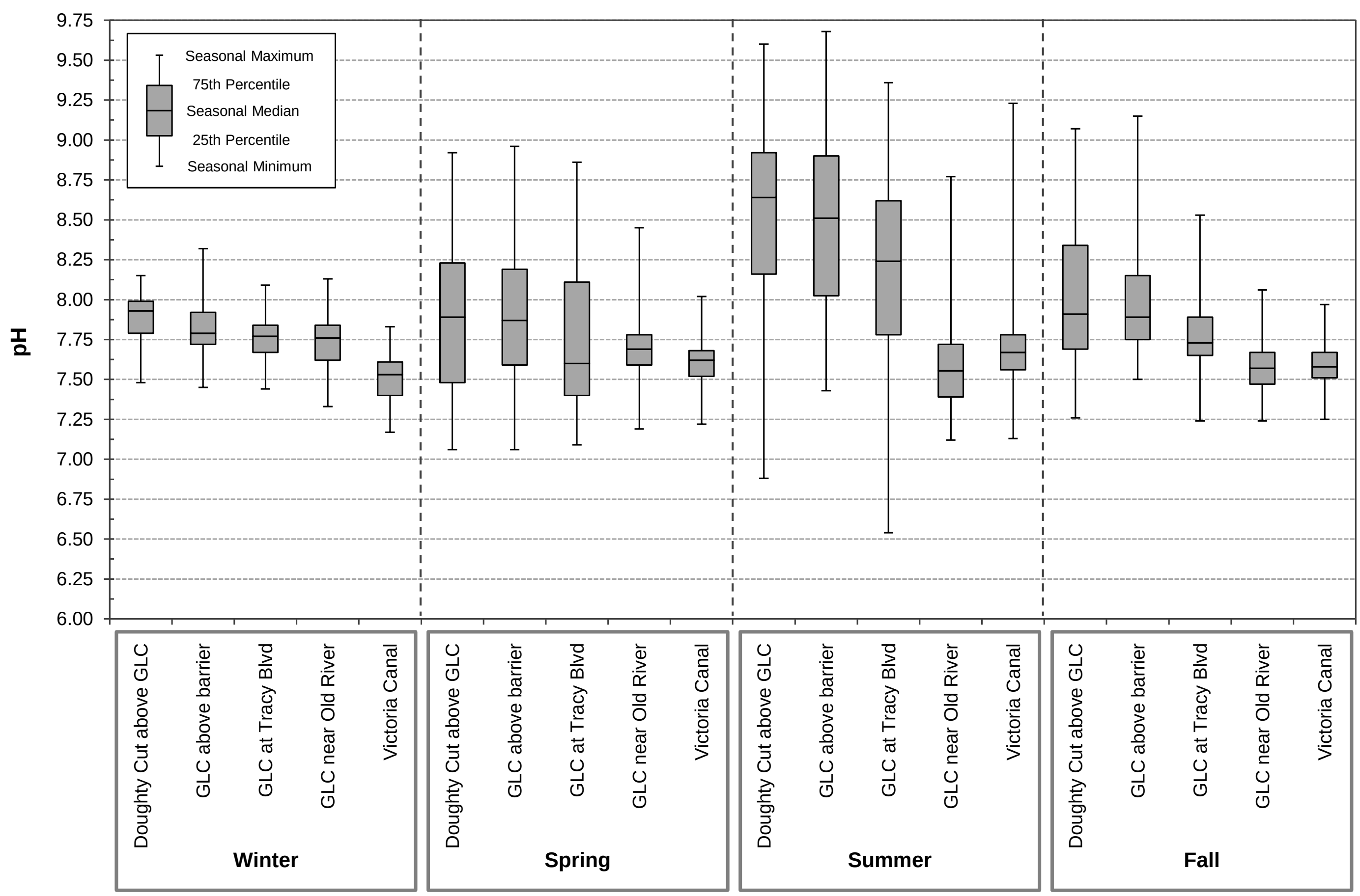
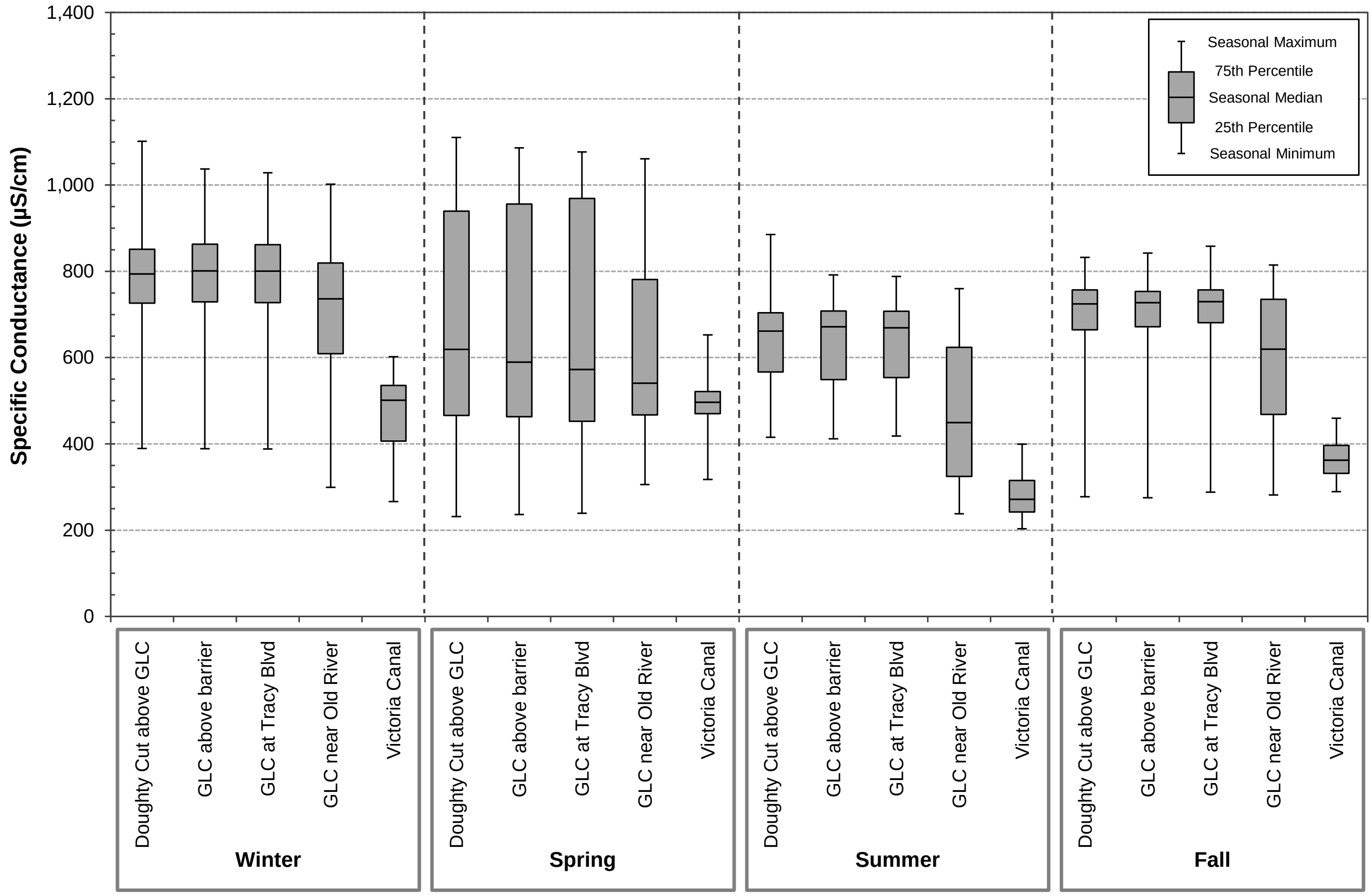


Figure 5-32: Box Plots for the Grant Line and Victoria Canal stations



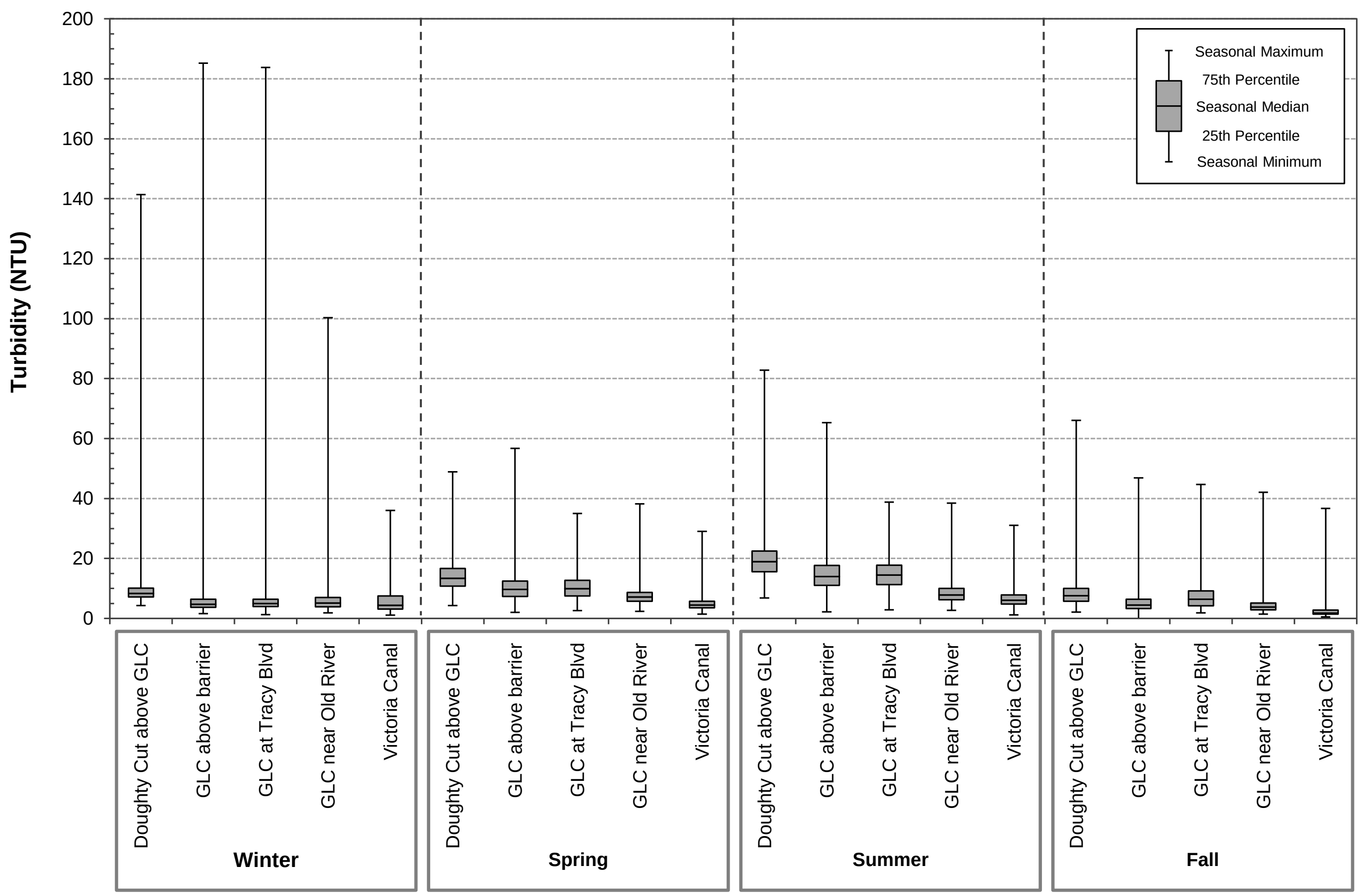


Figure 5-32: Box Plots for the Grant Line and Victoria Canal stations

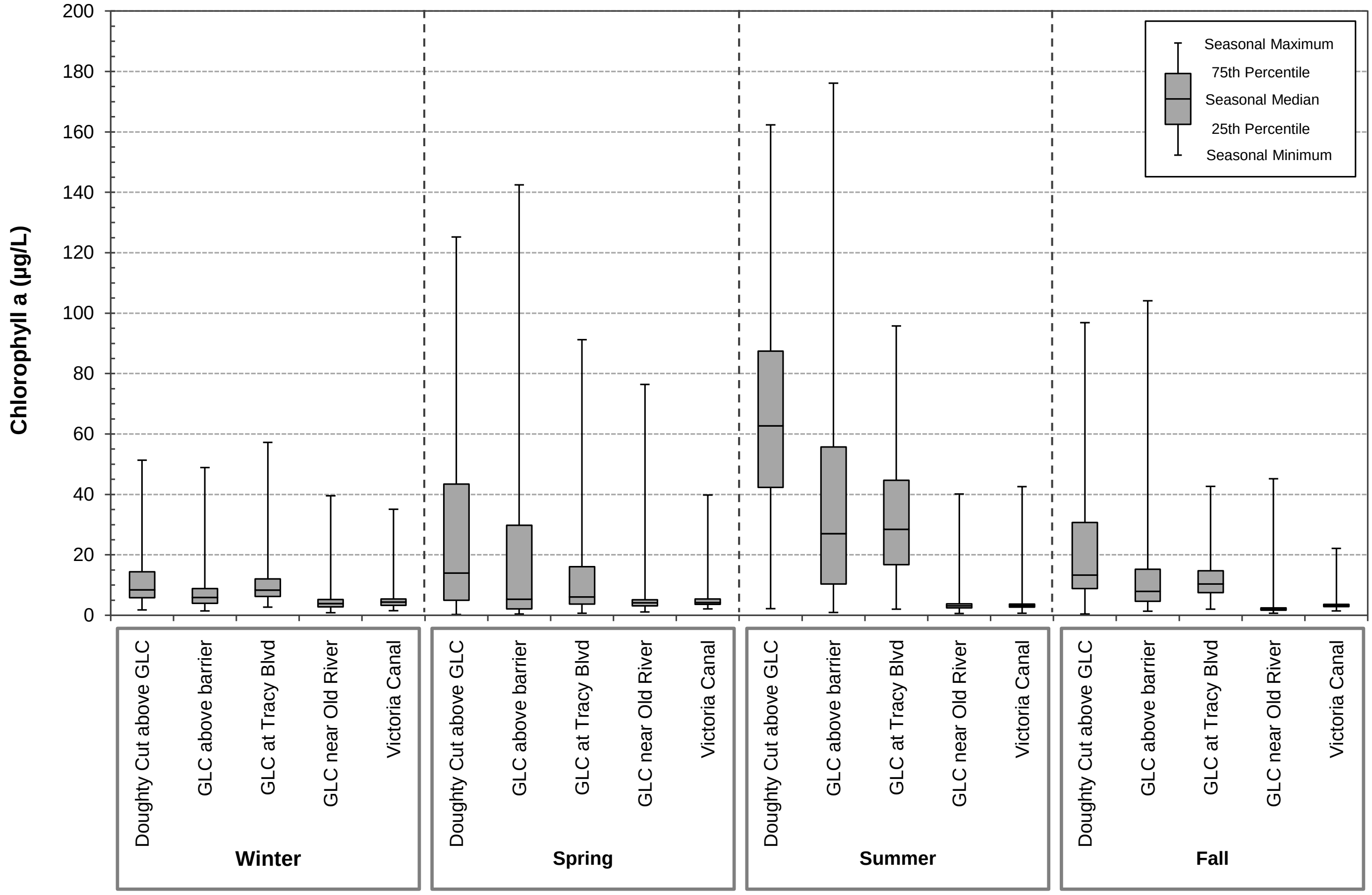
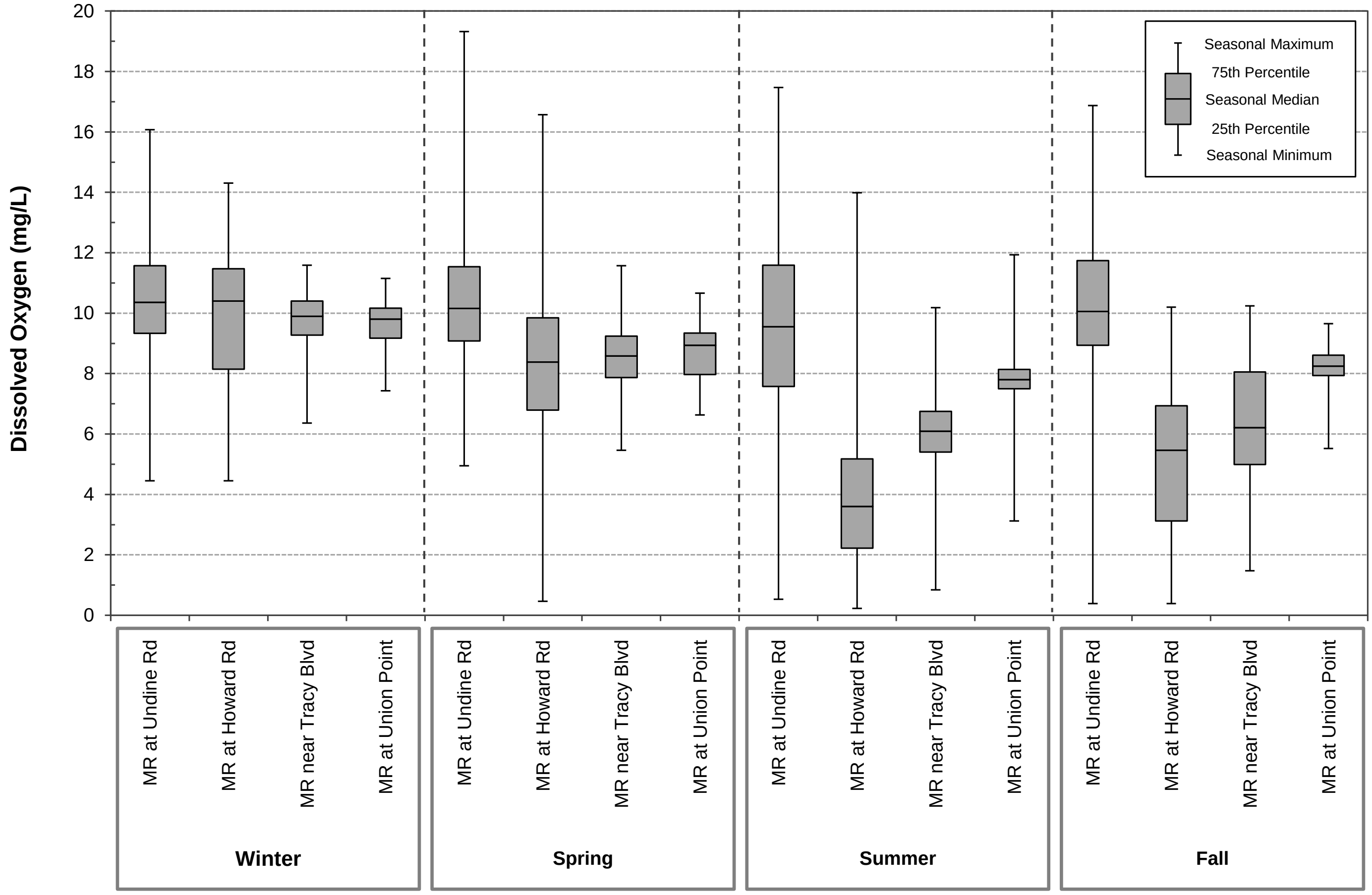


Figure 5-32: Box Plots for the Grant Line and Victoria Canal stations



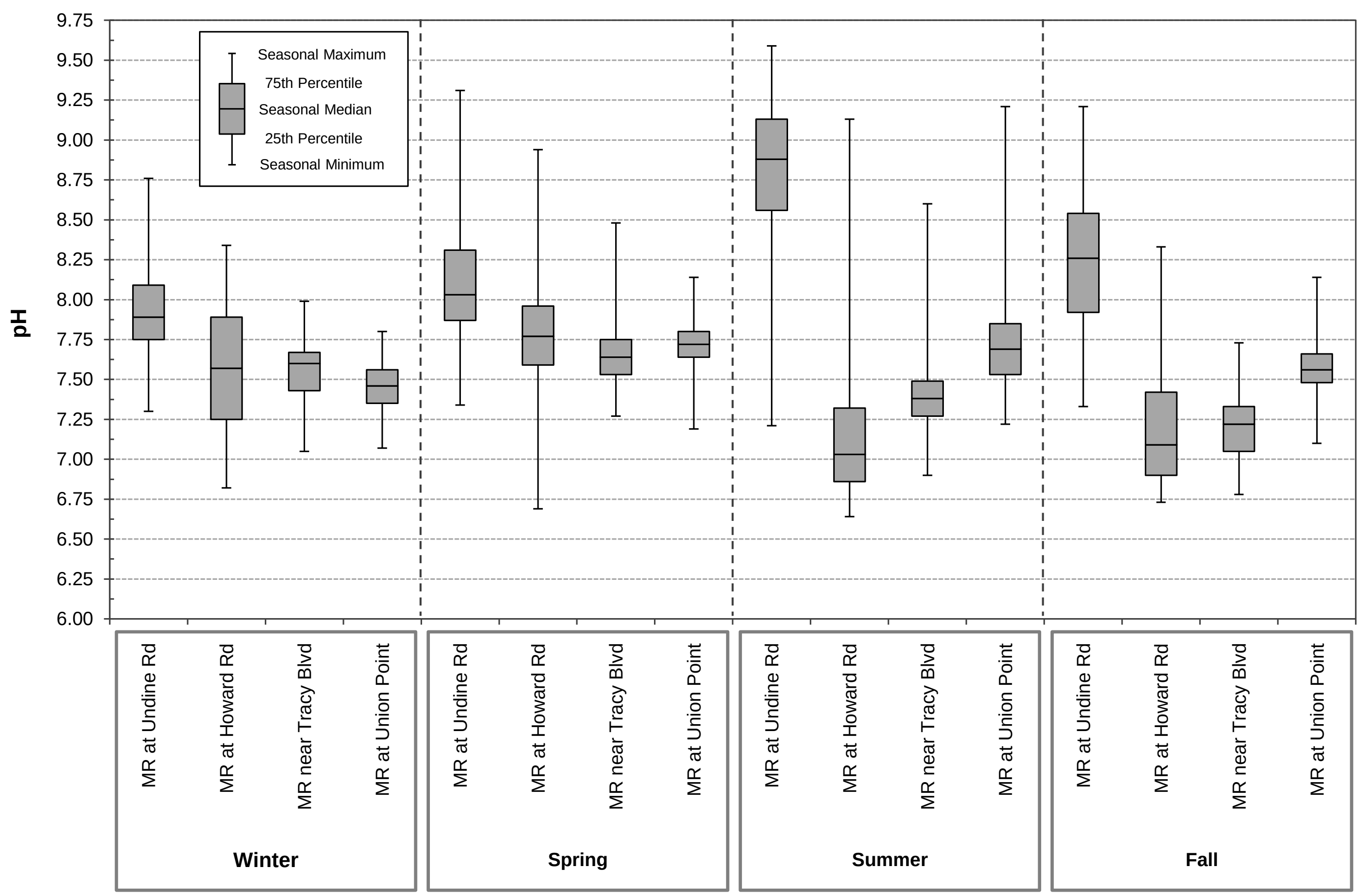
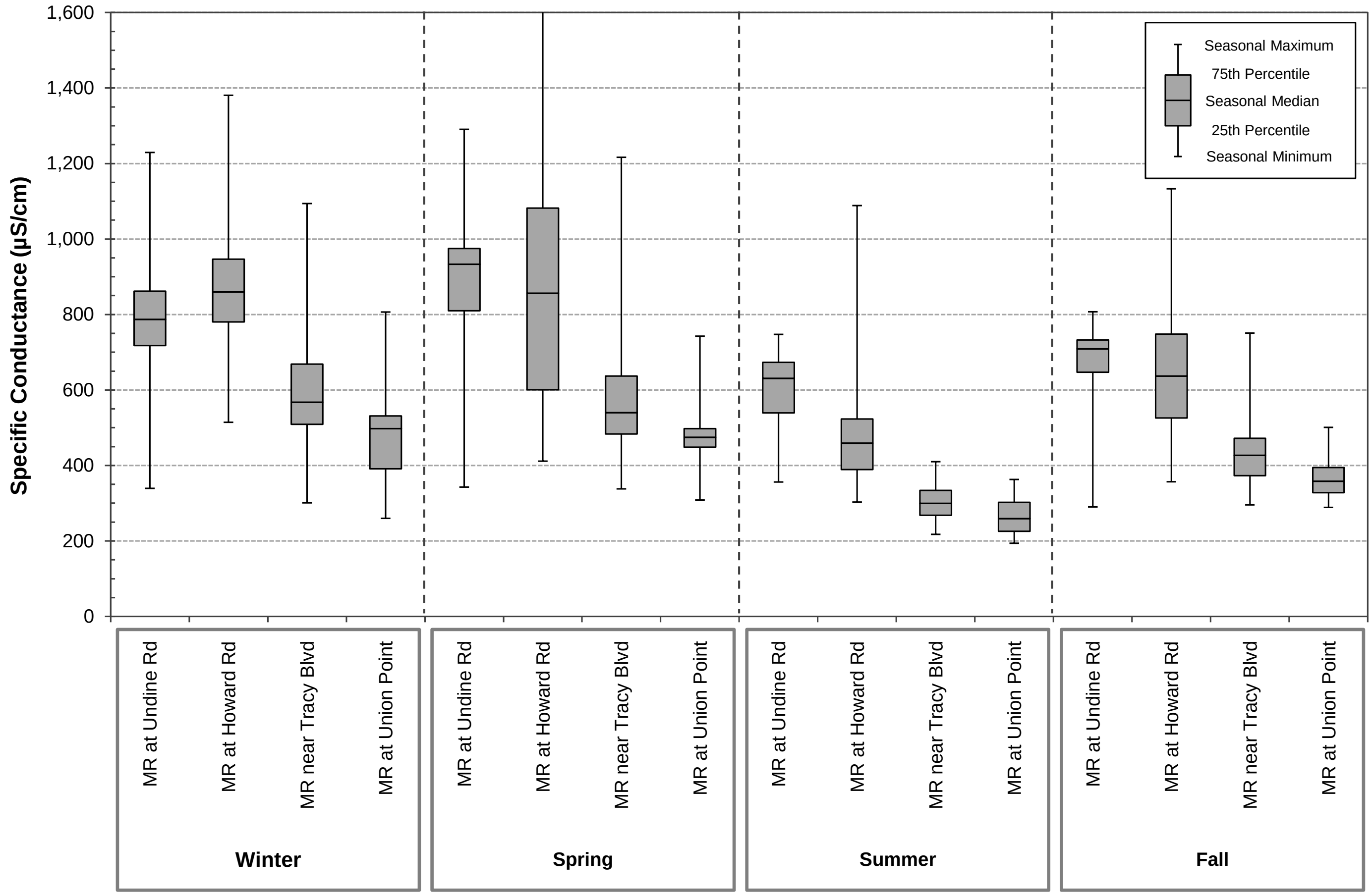


Figure 5-33: Box Plots for the Middle River stations



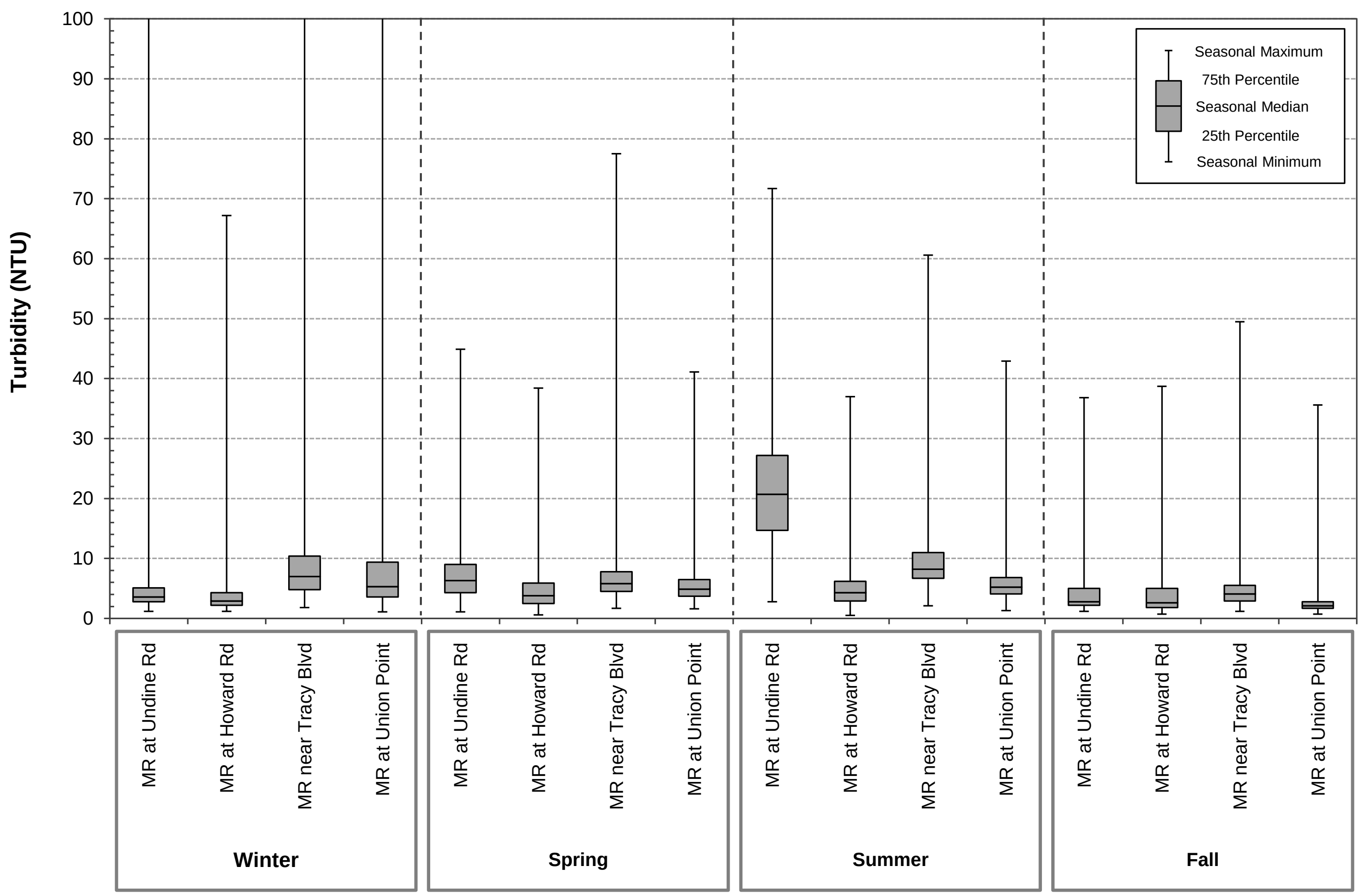


Figure 5-33: Box Plots for the Middle River stations

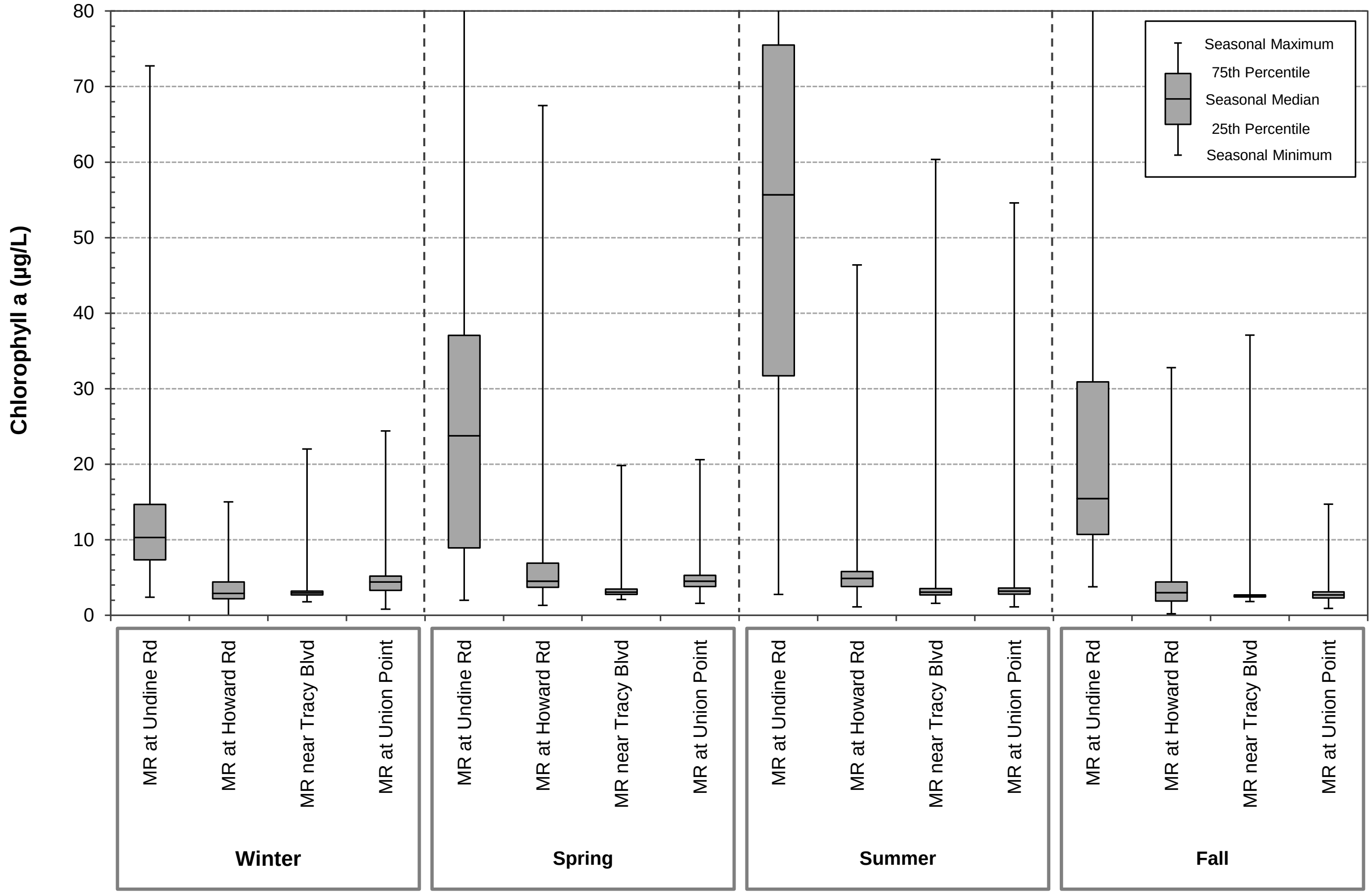
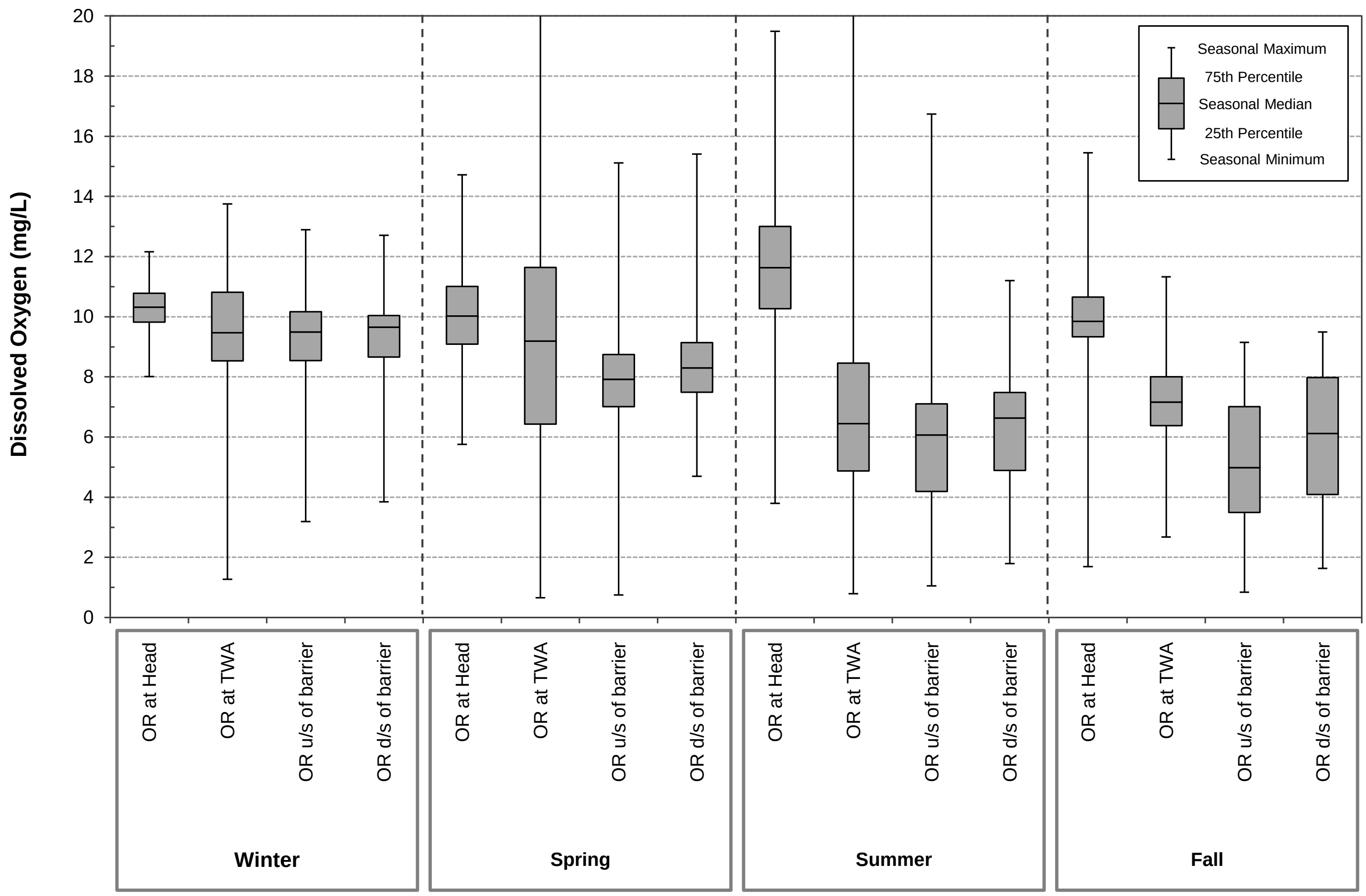


Figure 5-33: Box Plots for the Middle River stations



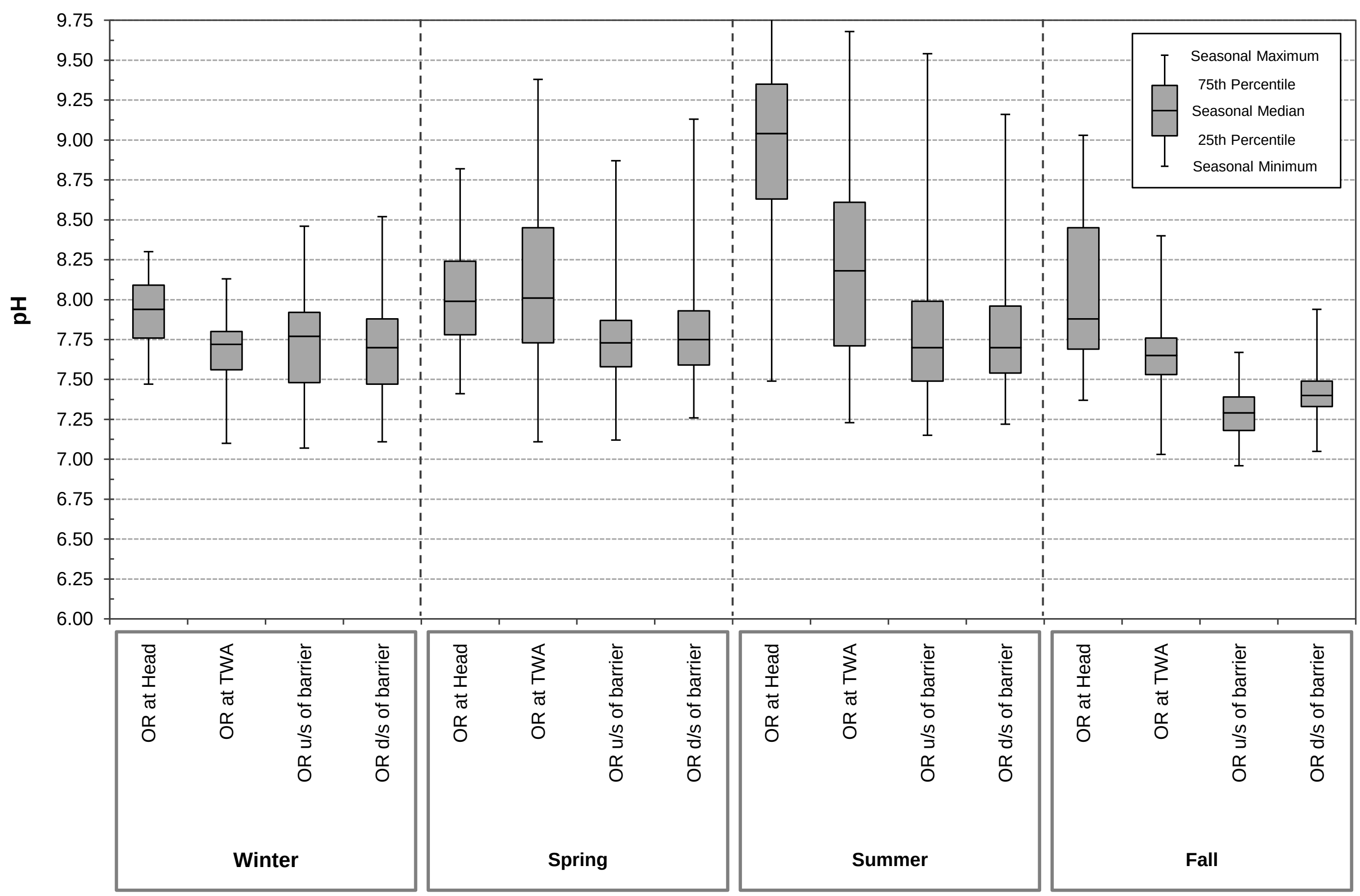
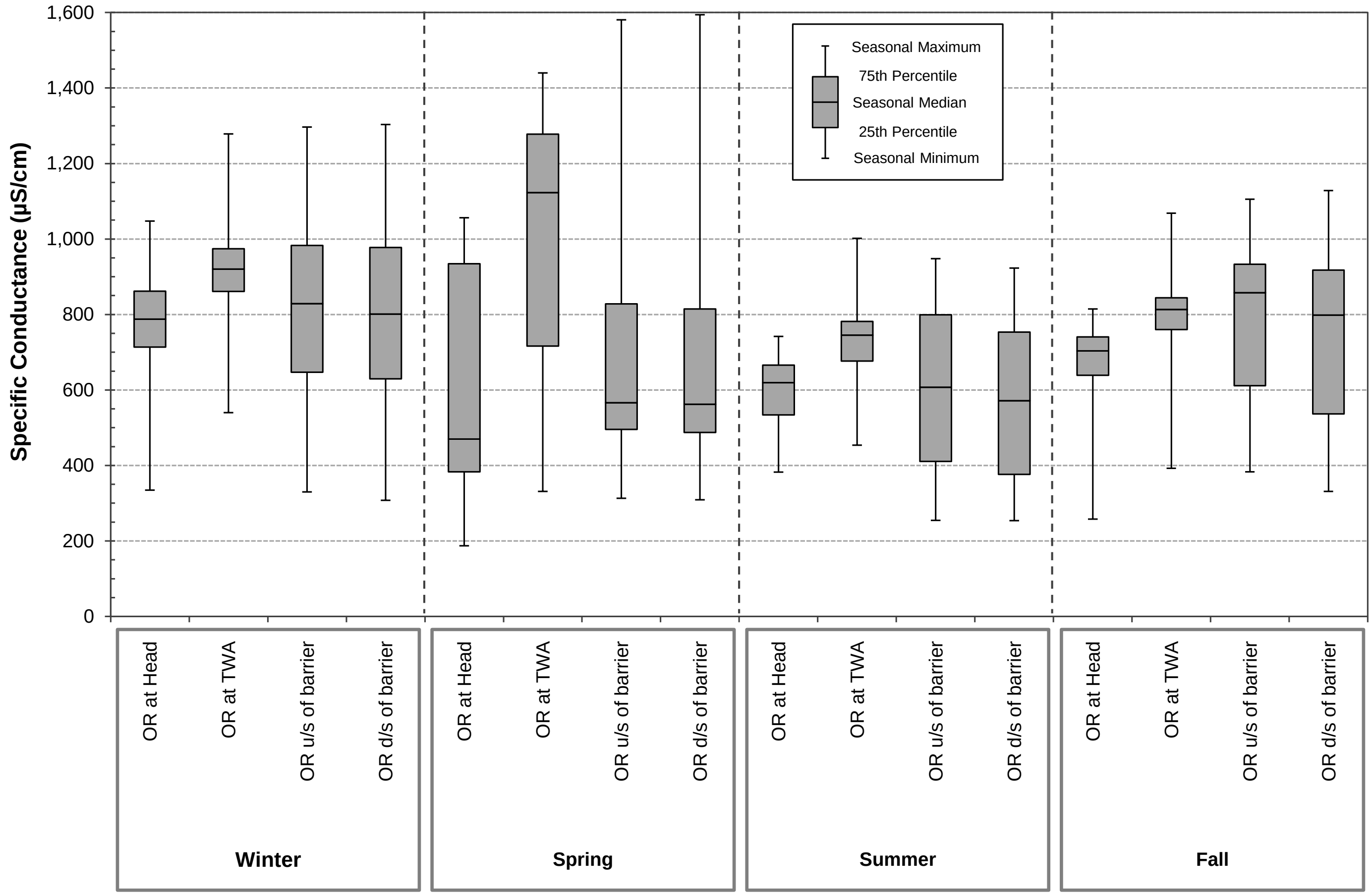


Figure 5-34: Box Plots for the Old River stations



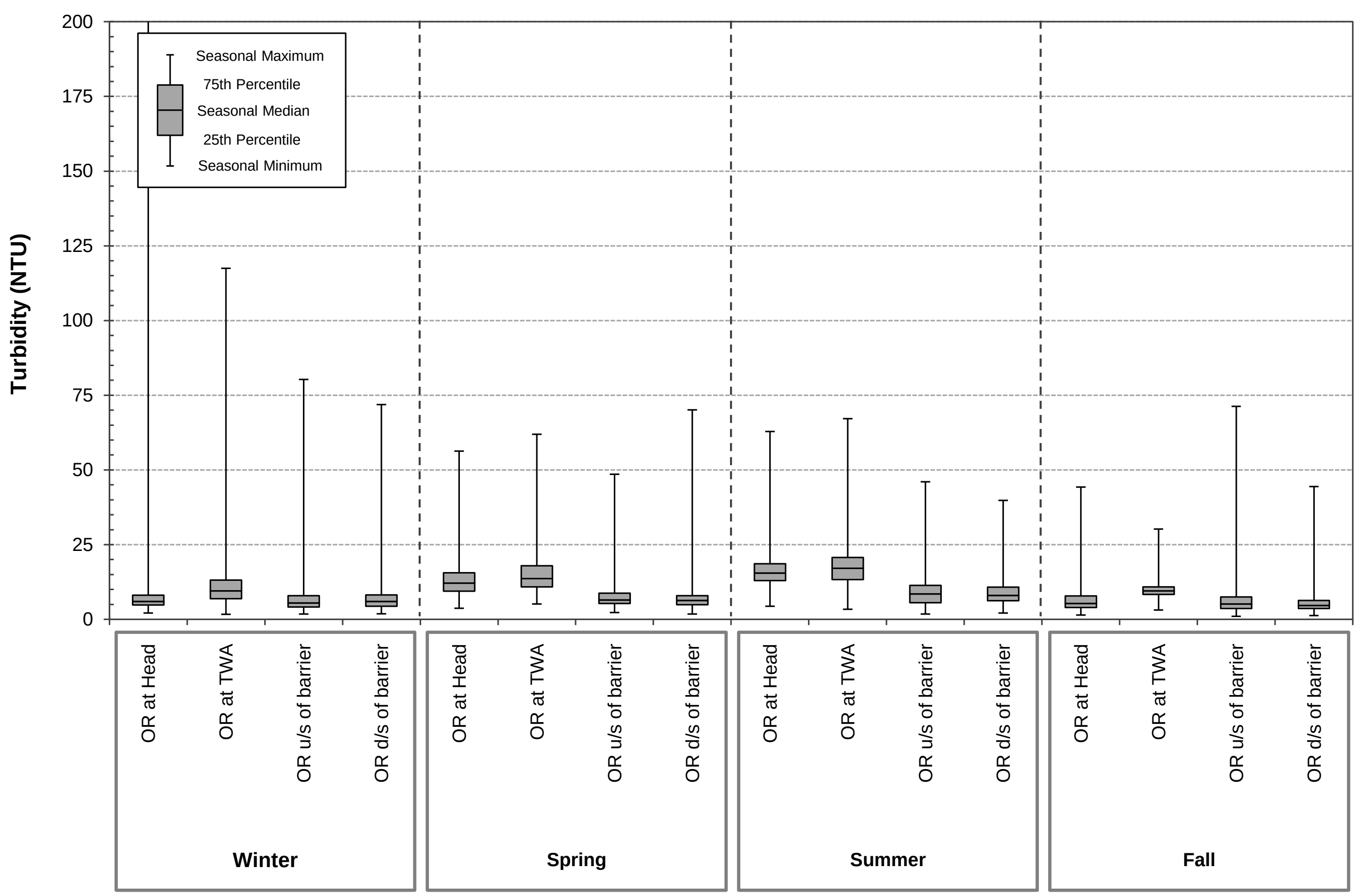


Figure 5-34: Box Plots for the Old River stations

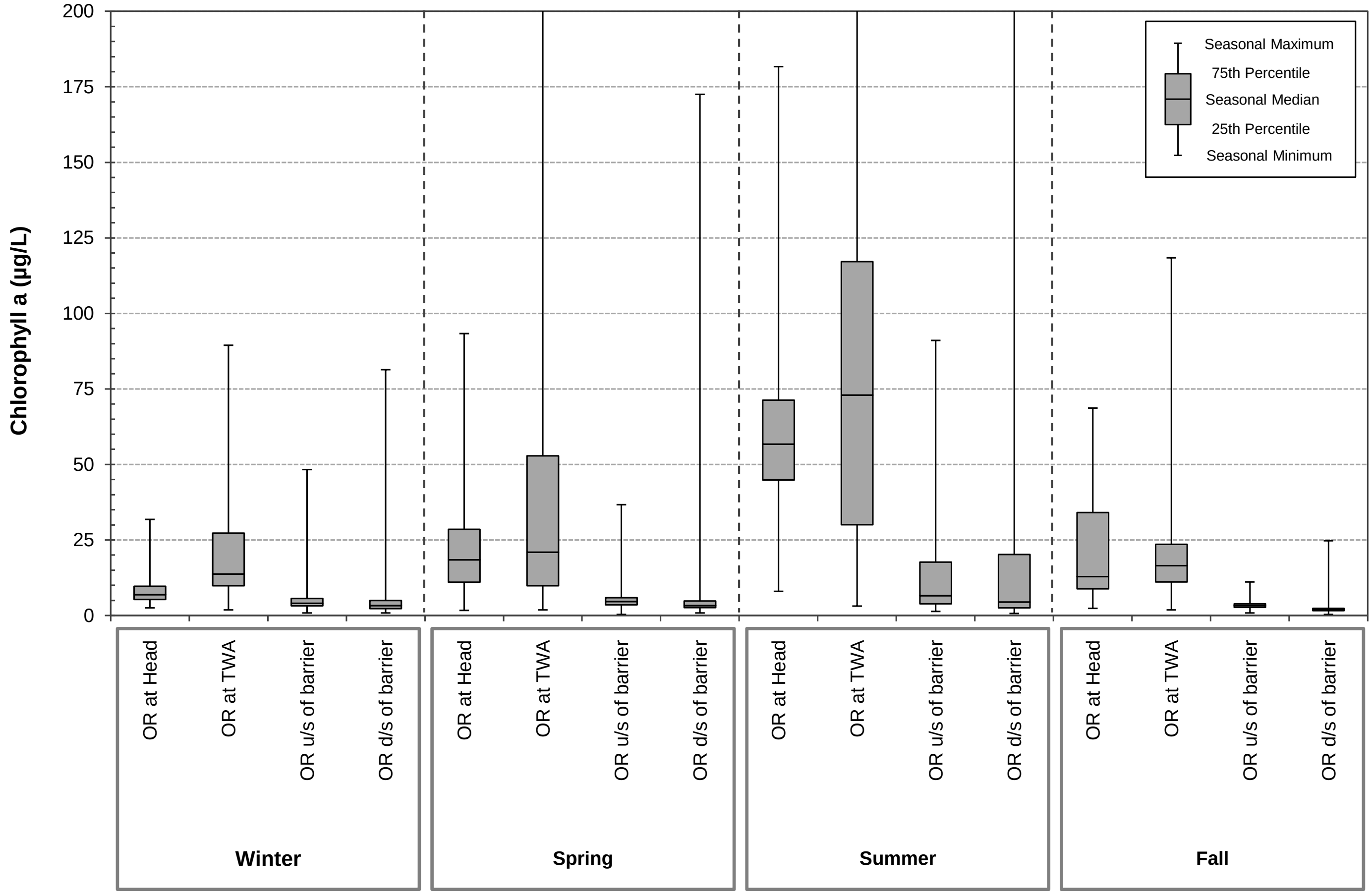


Figure 5-34: Box Plots for the Old River stations

Victoria Canal

- The water quality data measured at Victoria Canal is visibly different than the data collected at most of the continuous stations located on Grant Line Canal, Middle River, and Old River (Figure 5-32 and Table 5-4). This is most likely due to the Sacramento River's flow which effects Victoria Canal more compared to the rest of the south Delta stations.

- The average turbidity and chlorophyll *a* values for all four seasons at Victoria Canal are visibly lower than those values observed at most of the other stations in the South Delta. Turbidity values were typically between 4 and 10 NTU throughout the year with slightly lower values in the fall, which averaged around 2 NTU. Similarly, chlorophyll *a* values were low throughout 2012, usually between 3 and 7 µg/L.

- The observed pH values at Victoria Canal were low and had little variability during the entire year, which could be related to the low chlorophyll *a* values at this site. Typically, pH values ranged between 7.47 and 7.69 during 2012. Only 1% of Victoria Canal's pH readings exceeded 8.5 units which all occurred in the month of July 2012 (Figure 5-14 and 5-17)

- Dissolved oxygen concentrations were also fairly consistent during 2012. Monthly mean dissolved oxygen readings ranged from 7.82 to 10.33 mg/L during the entire year. Victoria Canal did not have a single dissolved oxygen reading of less than 5 mg/L during 2012 (Figure 5-5)

Grant Line Canal

- The Doughty Cut above Grant Line Canal, Grant Line Canal above the GLC barrier, Grant Line Canal at Tracy Blvd, and Grant Line Canal near Old River stations all had almost identical specific conductance values during the winter, spring, and fall of 2012 (Figure 5-32). Of these four stations, Grant Line Canal near Old River had lower specific conductance values during summer of 2012. Average specific conductance values at this station were about 200 µS/cm lower than the other three stations during July. Most likely, the water from nearby Old River is mixing with the water from Grant Line Canal near this station causing the typical specific conductance values to be lower.

- The Doughty Cut above Grant Line Canal, Grant Line Canal above the GLC barrier, and Grant Line Canal at Tracy Blvd stations had large increases in chlorophyll *a* concentrations during the spring and summer, indicating an increase in primary productivity and higher rates of algal photosynthesis in the water nearby these stations (Figures 5-29 and 5-32). These three stations also had increased pH values and highly variable dissolved oxygen concentrations during the summer (Figures 5-5 and 5-14). The Grant Line Canal near Old River station had a couple of periods of increased chlorophyll *a* concentrations during the spring and summer, but mostly stayed consistent throughout the year.

- Doughty Cut above Grant Line Canal, Grant Line Canal above the GLC barrier, and Grant Line Canal at Tracy Blvd all had high numbers of pH readings with values greater than 8.5. Of these three, the Doughty Cut station, had the highest number with 7,087 pH standard exceedences (Figure 5-17). In contrast, Grant Line Canal near Old River had a much lower number of pH standard exceedences with a total of 40 during the year. This trend in pH standard exceedences corresponds well with the trend in chlorophyll *a* concentrations at these stations. Stations with higher chlorophyll *a* concentrations, indicating higher rates of algal photosynthesis, also had increased pH values and more pH standard exceedences.

- The stations closest to the Grant Line Canal barrier, GLC above Barrier and GLC at Tracy Blvd, had the most dissolved oxygen exceedences in summer of 2012 (Figure 5-8). Grant Line Canal above

Barrier had significantly higher dissolved oxygen concentrations than Grant Line Canal at Tracy Blvd from July through November ($p<0.03$; Table 5-16).

- Turbidity values were fairly consistent at all four of the Grant Line Canal stations. Each Grant Line Canal station experienced elevated turbidity values towards the end of December due to storm events that resulted in increased runoff (Figure 5-26).

Middle River

- Middle River at Union Point had the lowest and least variable specific conductance values of all of the stations located along Middle River throughout most of 2012 (Figure 5-24). As with the Victoria Canal station, Middle River at Union Point may be more influenced by water from the Sacramento River. This may be the case, but less so, for the Middle River near Tracy Blvd station.

- The three Middle River stations at Undine Road, Howard Road, and near Tracy Blvd followed similar trends in specific conductance with increased values during April followed by decreased specific conductance during summer (Figure 5-24).

- Middle River at Undine Road had high concentrations of chlorophyll *a* particularly during the spring, summer, and early fall, indicating that photosynthetic activity was occurring near this station during these months (Figure 5-30) In addition to the increase in chlorophyll *a* concentrations, the Undine Road station had elevated pH values and periods of supersaturated dissolved oxygen concentrations during the same time period (Figures 5-6 and 5-15). The remaining three stations had brief periods of increased concentrations of chlorophyll *a* observed in spring or summer, but not as dramatic as Middle River at Undine Road (Figure 5-30).

- Middle River at Undine Road had a high number of pH readings with values greater than 8.5 with 29% of the total samples exceeding 8.5 units. Middle River at Union Point did not have any pH exceedences during 2012. The Howard Road and Tracy Blvd stations had 261 and 5 pH standard exceedences, respectively (Figure 5-18).

- Middle River at Howard Road had significantly lower dissolved oxygen concentrations than the three other Middle River stations during summer and fall ($p<0.03$; Tables 5-11 and 5-12). The low dissolved oxygen concentrations observed at the Howard Road station could be due to high summer water temperatures, low flow conditions, and high biological oxygen demand. Elevated spring and summer chlorophyll *a* concentrations observed at Middle River at Undine Road indicate algal blooms are occurring upstream of the Howard Road site. As the algae observed at Undine Road dies off and moves downstream, there is a possibility that oxygen levels at Howard Road are significantly affected by bacteria, which are consuming oxygen as they breakdown the algal biomass.

- Middle River at Howard Road also had the highest number of dissolved oxygen standard exceedences out of all of the South Delta stations. In 2012, the Howard Road station had 10,890 dissolved oxygen samples with values less than 5.0 mg/L (Figure 5-9). Most of these standard exceedences occurred in the summer with 73% of the total number of samples exceeding the standard. Middle River at Undine Road and near Tracy Blvd had lower numbers of dissolved oxygen standard exceedences with 640 and 3,573, respectively. Dissolved oxygen concentrations on Middle River at Union Point never fell below 5 mg/L during 2012.

- Turbidity values weren't that variable at the Middle River stations. Each station experienced elevated turbidity values towards the end of December due storm events that resulted in increased runoff (Figure 5-28).

Old River

- The Old River at Head station had the most pH standard exceedences in 2012 with a total of 9,912 (28% of the total number of samples) (Figure 5-19). Most of these standard exceedences occurred during the summer with 82% of the total number of samples exceeding the standard. Old River at Head and Old River at Tracy Wildlife Association had high concentrations of chlorophyll *a,* particularly during the spring, summer, and early fall, indicating that photosynthetic activity was occurring near these stations (Figure 5-34). Old River at Tracy Wildlife had a total of 4,790 pH exceedences (14% of the total samples) during 2012.

- The stations upstream and downstream of the ORT barrier had elevated chlorophyll *a* concentrations during summer of 2012 (Figure 5-31). These stations had the most pH exceedences during summer, but were not as high as the two other Old River stations (Figure 5-19).

- Old River at Tracy Wildlife Association had higher specific conductance values than the three other Old River stations, particularly during spring (Figure 5-34). Monthly mean specific conductance values at Old River at Tracy Wildlife Associations range from 638 µS/cm in May to 1,302 µS/cm in April.

- The stations closest to the ORT barrier had higher total number of dissolved oxygen exceedences during 2012 than the stations further upstream (Figures 5-10 and 5-13). The Old River upstream of the barrier station had 8,207 total exceedences (23% of all samples) and the station downstream had 5,791 total exceedences (about 17% of all samples). For six months of the year, Old River downstream of the ORT barrier station had significantly higher dissolved oxygen readings in comparison to the upstream station. The differences between the stations was not dependent on season ($p<0.03$, Table 5-18).

- Turbidity values were similar to the Grant Line Canal and Middle River stations, which stayed relatively consistent throughout 2012 except for an elevated period at the end of December due to storm events that resulted in increased runoff (Figure 5-28).

CONCLUSIONS AND RECOMMENDATIONS

Continuous data collection at the 13 South Delta monitoring locations in 2012 revealed the following overall trends:

- Old River at Tracy Wildlife Association and Middle River at Howard Road had some of the highest specific conductance values during 2012, especially during spring. Victoria Canal and Middle River at Union Point had some of the lowest specific conductance values throughout 2012. Water quality at Victoria Canal and Union Point may be more influenced by the Sacramento River.
- Turbidity values at all of the South Delta stations remained relatively consistent throughout 2012, except towards the end of December, when increased runoff from storm events elevated turbidity values at most stations.
- The stations with elevated chlorophyll *a* values in the spring, summer, and early fall were Doughty Cut, Grant Line Canal above the GLC barrier, Grant Line Canal at Tracy Blvd, Middle River at Undine, Old River at Tracy Wildlife Association, and Old River at Head. Victoria Canal, Grant Line Canal near Old River, Middle River at Union Point, and Middle River near Tracy Blvd, all had low chlorophyll *a* values throughout 2012.
- The stations with higher chlorophyll *a* values listed above also had some of the highest pH values and supersaturated dissolved oxygen concentrations during the warmer months.

- The stations with low chlorophyll *a* values listed above had lower pH values throughout the year.
- Middle River at Howard Road, Old River upstream of the ORT barrier, and Old River downstream of the barrier had some of the lowest dissolved oxygen concentrations in the spring, summer, and early fall. Of these three stations, Middle River at Howard Road had the lowest concentrations.

DWR staff have the following recommendations for future water quality studies in the South Delta:

- Additional studies and analyses are necessary to determine the relationships between dissolved oxygen concentrations and factors such as algal biomass, biological oxygen demand, and flow at the area between Middle River at Howard Road and Middle River near Tracy Blvd. Similar studies and analyses should be done at the stations nearby the ORT and GLC barriers since they also recorded low dissolved oxygen levels during the spring, summer and fall.
- Data from the specific conductance monitoring stations on Sugar and Paradise Cuts should be analyzed to help understand the influences of these water bodies on specific conductance values at Old River at Tracy Wildlife Association which is a quarter mile downstream of the Old River at Tracy Road Bridge specific conductance compliance station.
- Studies should be done to determine the sources of the brief periods of highly elevated specific conductance values at Middle River at Howard Road and Undine Road.
- DWR staff will be conducting long-term trend analyses to reveal any changes in water quality parameters at the 13 South Delta stations.
- Conduct bathymetric survey of Middle River between Undine Road and Union Point to define flow capacity for input into computer models for SWP/Delta operations.

Monitoring will continue in 2013 at all 13 stations to supplement: (1) the existing time-series record, (2) provide historical data, and (3) to meet the requirements outlined in the 401 Water Quality Certification for the Temporary Barriers Project.

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